2/7/00

FINAL REPORT

Hydrologic Evaluation for Bunker Hill Mine TMDL Compliance

Bunker Hill Mine Water Management
Kellogg, Idaho

Prepared by

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Under subcontract to

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Prepared for

U.S. Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, Washington 98101

Contract No. 68-W-98-228
Work Assignment No. 021-RI-CO-105G

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1.0 Introduction

This document presents a hydrologic evaluation of the historic mine water flow from the Bunker Hill Mine Kellogg Tunnel (KT) with respect to flow in the South Fork of the Coeur d'Alene (SFCdA) River in northern Idaho. This evaluation is part of the Bunker Hill Mine Water Management RI/FS being conducted by the United States Environmental Protection Agency (USEPA) to develop a long-term management system for the Bunker Hill mine water.

The long-term mine water management system will include mine water collection and treatment. The size and configuration of these components is directly tied to the magnitude of the mine water flows. The treatment system will discharge the treated mine water into Bunker Creek, which is a tributary to the river. The discharge will be monitored and must comply with a discharge permit based on total maximum daily loads (TMDLs) being established for the river by the EPA for cadmium, lead, and zinc. Since TMDLs are pollutant load-based depending on the river flow rate, the flow relationship between the mine and the river is critical for treatment plant sizing and configuration. This memorandum presents the results of comparisons performed between historic mine and river flows to facilitate development of the treatment plant and the overall mine water management system.

The best approach for developing selection and design criteria for the treatment plant and overall mine water management system is to use historic flow data to indicate possible future flows that the system may need to control. The shortfall of this approach is that historic flows are just that—they are historic and therefore cannot be true representations of future flows; thus, their use must be tempered with reasonable precaution. An approach to help predict future flows is to try and develop a correlation between the historic mine and river flows. If a correlation exists, then mathematical tools can be used to estimate the probability of future flows. For example, if the mine flows correlate well with river flow, then various river return frequency flows can be used to estimate associated mine flows, such as 10-, 50-, or 100-year design flow events. It could even be possible to create artificial mine hydrographs using river hydrographs. This would provide good flexibility for evaluating numerous possible flow situations that the mine water management system may need to control. If no good correlation exists between the historic mine and river flows, then this approach will not be possible. In this event, careful consideration must be given to the applicability of the historic flows to provide good basis for selection and design of the mine water management system.

1.1 Background

The Bunker Hill Mine is located within and below hillsides just south of Kellogg, Idaho, in the Silver Valley of northern Idaho (Figure 1). These hillsides range in elevation from 2,300 feet at the valley floor to 6,300 feet, which is the top of Kellogg Peak, located above the mine. These hills and Kellogg Peak get considerable amounts of snowfall. Silver Mountain ski resort is located on Kellogg Peak. Snow accumulations of several feet are common, with water contents of 2 to 4 feet. Total precipitation in the town of Kellogg averages about 30 inches per year.

The mine was built to obtain access to ore bodies oriented along major faults. These faults strike in a northwesterly to westerly direction and dip to the southwest between 50 and 80 degrees, which is into the hillsides away from the river. The mine extends vertically over 1 mile from discovery cuts, some 3,600 feet above sea level, to the 31 Level, 1,600 feet below sea level. The mine contains more than 150 miles of drifts and 6 miles of major inclined shafts. The Kellogg Tunnel on the 9 Level serves as the major access route to the mine workings. Figure 2 is a general cross section of the mine. Mine levels are located about 200 vertical feet apart, and are offset about 100 to 200 feet horizontally as a result of the dip of the ore bodies.

Water enters the mine through three primary inflow mechanisms: surface water inflow, inflow from the groundwater system to the upper workings (9 Level and above), and inflow from groundwater to the submerged workings (11 Level and below, including groundwater inflow on the 10 Level). Surface water inflow occurs where workings have come close enough to intercept a portion of the surface water. Surface cavings of underground stopes (that is, Guy Caving area in Milo Gulch) and workings in the vicinity of surface water flows (that is, Deadwood Creek through Inez Shaft) are some examples of the larger known surface water inflows. Groundwater inflow to the upper workings occurs through faults (for example, Cate, Buckeye, Sullivan, Dull, Katherine, and Marblehead), fractures, and block bedding fractures and jointing. The volume of water transmitted by an individual feature is a function of the availability of water, the conductivity of the feature, and the area that is intersected by mine workings. Groundwater inflow to the submerged workings likely occurs through faults, fractures, and jointing that is intersected by the lower levels of the mine.

Gravity flow from the upper workings is collected on the 9 Level and flows out of the Kellogg Tunnel via a ditch in the tunnel floor. The Kellogg Tunnel, and most other tunnels and drifts, was constructed with a slope to allow gravity drainage out the portal. The elevation of the Kellogg Tunnel portal is approximately 2,360 feet above mean sea level. A portion of this upper workings water likely continues below 9 Level because of flows that are not intercepted by the 9 Level drift. These flows combine with groundwater inflow, and become part of the mine pool in the submerged workings. Currently, a pump system is located in Shaft No. 2 to maintain the elevation of the mine pool at about 1,970 feet (30 feet below 11 Level). A variety of pumping scenarios were used over the last 30 years to keep the mine dewatered to lower working levels. Mine dewatering prior to 1991 used a pump system on the 23 Level to allow access to ore in lower levels. This required increased pumping rates when compared to the current scenario, which averages about 700 to 800 gallons per minute (gpm). Without active pumping, the elevation of the mine pool would rise and eventually reach the elevation of 9 Level and flow by gravity out of the Kellogg Tunnel. The elevation of the SFCdA River adjacent to the Bunker Hill Mine is approximately 2,240 feet above mean sea level.

Work has been conducted by CH2M HILL and by a number of researchers through the University of Idaho that shows, in general, that Kellogg Tunnel flows peak in the spring in response to melting snow on the hills above the mine, and then decrease to a baseline flow condition in the fall and winter of each year. Current and historic mining and mine dewatering operations have influenced seasonal KT flow rates. Tailings backfilling methods (sandfilling) were used throughout the 1970s and into the 1980s. This process used 200 to more than 300 gpm, 24 hours per day, to convey the sandfill back into the mine. The water that separated from the tailings would then join the other mine waters and be pumped back up to the 9 Level ditch and flow out of the Kellogg Tunnel. A Parshall flume located outside the Kellogg Tunnel portal is used to measure the mine discharge.

Water that flows out of the Kellogg Tunnel requires treatment to reduce metals and increase pH before it can be discharged to Bunker Creek. The current Central Treatment Plant (CTP) will need upgrading to meet the discharge requirements for the Bunker Hill Mine that are being developed (currently in draft) through EPA's TMDL process (EPA, 1999). The draft TMDLs are load-based discharge limits that vary depending on SFCdA River flow. The relationship between Kellogg Tunnel flows that require treatment and SFCdA River flows is critical for TMDL compliance and for development of the mine water management system. This relationship is important because if Kellogg Tunnel flow increases, then the amount of water requiring treatment increases. If this occurs as SFCdA River flow increases, then the allowable metal load (lb/day) that can be discharged will increase depending on the size of the river flow increase. Alternately, if Kellogg Tunnel flow increases while SFCdA River flow decreases, the mine water management and treatment system will have to be more robust to achieve the same degree of flexibility, such as storing the mine water for later treatment. The size and configuration of possible treatment and storage systems thus requires some understanding of the relationship between mine and river flows.

Additional information on mine water inflow and intra-mine flow is presented in the *Acid Mine Drainage – Bunker Hill Mine Water Conceptual Model* (CH2M HILL, 1999b). A review of the hydrogeologic relationship between the SFCdA River and the Bunker Hill Mine is presented in the *Analysis of Bunker Hill Mine Pool and South Fork Coeur d'Alene River Hydraulic Relationships* memorandum (CH2M HILL, 1999a).

1.2 Purpose

The primary purpose of the hydrology evaluation was to evaluate the relationship between Kellogg Tunnel and SFCdA River flows to help develop selection and design criteria for mine water management systems that comply with the upcoming TMDL-based requirements. A secondary purpose was to develop an approach for using this hydrology information for subsequent TMDL compliance evaluations.

2.0 Hydrograph Development

The first step in the evaluation was to develop historical hydrographs for the Kellogg Tunnel and SFCdA River. A hydrograph presents flow rate versus time for a given location, such as the Kellogg Tunnel at the portal, and the SFCdA River at the Pinehurst gauging station. This section discusses the selection of historical flow data and the development of these hydrographs. Section 3 compares the two hydrographs.

2.1 Hydrology Data Sources

2.1.1 Kellogg Tunnel Data Sources

Hydrology data for the Kellogg Tunnel were obtained from several different sources listed in Table 1. Most of the data represent instantaneous flow readings at the Kellogg Tunnel. Most of these data sources are available through the CH2M HILL project library in Spokane. Table 1 summarizes the sources of flow data, the coverage period, the reported data type (for example, instantaneous flow measurement, average weekly flow, etc.), whether or not the data were included in developing the KT hydrographs, and comments on the data.

A review of data from all of the sources was conducted to remove questionable data, select one source in the event of data overlap, and to develop a data set for the KT hydrographs. The results of the data review are presented in Table 1. The rationale behind including or excluding a data set in the hydrologic evaluation are shown. A plot of all the KT data reviewed for possible use in developing the KT hydrographs is presented in Figure 3.

TABLE 1
Sources of Hydrologic Data for the Kellogg Tunnel

Data Source	Dates Covered	Data Type	Used to Develop KT Hydrographs	Data Use Comments
Bryson Trexler PhD Dissertation (1975)	12/1/72 - 11/22/74	Daily instantaneous KT flow measurements; some days are missing.	Yes	Dr. Trexler has been contacted and he confirmed the data.
NPDES Permit Monthly Discharge Monitoring Reports (DMRs) by The Bunker Hill Company (from John Riley files)	10/20/77 - 12/30/79	Daily instantaneous KT flow measurements; some days are missing.	Yes	DMRs were reported to the EPA.
Hydrographs showing KT flow (Erikson work, provided by John Riley)	10/1/78 - 9/22/84	Daily instantaneous KT flow measurements plotted as hydrographs; weekly data obtained from hydrographs.	No	Don't have daily instantaneous KT flow measurements. But, data agree with overlapping data from 77-79 DMRs and 80-82 Riley Database.
Electronic database provided by John Riley	1/1/80 - 12/31/82	Daily instantaneous KT flow measurements.	Yes	

TABLE 1
Sources of Hydrologic Data for the Kellogg Tunnel

Data Source	Dates Covered	Data Type	Used to Develop KT Hydrographs	Data Use Comments
NPDES Permit Monthly Discharge Monitoring Reports (from John Riley files)	1/1/83 - 8/31/84	Daily instantaneous KT flow measurements.	Yes	During all of 1983, the flume was operated at 95 percent submergence, because of accumulation of debris that clogged a trash rack located downstream from the flume. A 43 percent reduction in flow was recorded after cleaning the debris on 5/1/84 (Erikson, 1985). Data are corrected and used through 8/31/84.
Daniel Erikson MS Thesis (1985)	1/5/83 - 8/29/84	Average weekly KT flow measurements.	No	Not needed because data agree well with corrected flow reported in DMRs for the corresponding time period.
John Riley PhD Dissertation (1990)	1/25/83 - 10/31/85	Weekly/bi-weekly instantaneous KT flow measurements.	Yes	Data agree well with corrected flow reported in DMRs for the corresponding time period. Data are used from 9/1/84 through 10/31/85.
NPDES Permit Monthly Discharge Monitoring Reports (from Bill Hudson files)	1/1/86 - 12/31/89	Daily instantaneous KT flow measurements; some days are missing (recorded as flume stage reading).	Yes	
Misc. Files (Bunker Hill Tunnel Field Logs, Bunker Limited Partnership Reports, Jasberg Technical Services Monthly Mine Drainage Report)	10/15/91 - 2/28/93	Daily/Weekly instantaneous KT flow measurements (recorded as flume stage reading).	No	Data not representative of actual mine flow; water from upper workings was being diverted at the time.
Bill Hudson Field Notes	6/12/95 - 10/15/96	Daily/Weekly instantaneous KT flow measurements (recorded as flume stage reading).	Yes	There is an overlap period for data between Hudson's and Stefanoff's data set; both sets agree very closely. Starting on 7/11/96, data from Stefanoff's field notes are used, since they are recorded more frequently.
Jim Stefanoff Field Notes	7/11/96 - 5/15/97	Daily/Weekly instantaneous KT flow measurements (recorded as flume stage reading).	Yes	

TABLE 1
Sources of Hydrologic Data for the Kellogg Tunnel

Data Source	Dates Covered	Data Type	Used to Develop KT Hydrographs	Data Use Comments
CH2M HILL Mine Water Monitoring Program	11/13/98 - 9/10/99	Instantaneous KT flow measurements recorded at the flume	Yes	Flows were diverted into the submerged workings during a pipeline block during spring1999, data collected during this period are not representative of actual mine flows.
Kellogg Tunnel Flow Meter Readings maintained by Morrison Knudsen Corporation	9/1/98 - 3/17/99	Instantaneous KT flow measurements recorded continuously on a strip chart as stage readings.	Yes	Data entered into spreadsheet are daily average flow rates from KT.

2.1.2 SFCdA River Data Sources

Hydrology data from different gauging stations along the SFCdA River were obtained from the United States Geological Survey (USGS) Internet site. Several different USGS gauging stations have been used since 1966. Table 2 summarizes the gauging stations, dates of operation, and location along the river. Figure 1 shows the locations of the gauging stations. The Pinehurst gauging station, located down river from Pinehurst, Idaho, will be used by USEPA to establish cadmium, lead, and zinc TMDL-based discharge amounts for the CTP.

TABLE 2
South Fork Coeur d'Alene River USGS Data Sources

Gauging Station	Station #	Monitoring Dates	Comments
Elizabeth Park	12413210	8/12/87 – 9/30/98	Currently in operation.
Kellogg	12413250	4/1/74 – 10/19/82	Discontinued in 1982.
Pinehurst	12413470	8/12/87 – 9/30/98	Currently in operation.
Placer Creek	12413140	10/30/67 – 9/30/95 10/1/96 – 9/30/97	Discontinued October 1, 1995, to September 30, 1996.Currently in operation.
Silverton	12413150	11/9/67 – 9/30/88	Discontinued in 1988.
Smelterville	12413300	11/18/66 – 3/31/74	Discontinued in 1974.

Note: The data for the SFCdA River is presented as average daily flows (in cubic feet per second)

2.2 Development of the Kellogg Tunnel Hydrograph

A Kellogg Tunnel hydrograph was created by plotting the retained data described in Table 1. This hydrograph is presented in Figure 4 (the red plot), which also shows the hydrographs for the different gauging stations, as described below. Please note that the left scale of the plot corresponds to the KT flows in gpm, and the right scale corresponds to river flow in cubic feet per second (cfs) at the various gauge locations.

2.3 South Fork Coeur d'Alene River Hydrograph

The gauging station near Pinehurst plays a particularly important role in the compliance evaluation. This station has been selected by USEPA as the basis for calculating the TMDL waste load allocation for the CTP. The Pinehurst station has been operational since August 1987 (see Figure 4), while the Kellogg Tunnel data hydrograph goes back to 1972. Therefore, no direct comparison of the KT hydrograph can be made to the Pinehurst hydrograph prior to August 1987. This is unfortunate since the larger KT flow years occurred prior to 1987. These larger flow years are important for configuring and sizing the mine water management system, and especially the treatment plant. To help overcome this lack of Pinehurst flow data, and to provide some indication of what the Pinehurst flows may have been prior to August 1987, estimated Pinehurst flows prior to 1987 were developed for comparison to the Kellogg Tunnel flows. The procedure for developing these estimated Pinehurst flows, also referred to as synthetic hydrographs, is described below.

2.3.1 Pinehurst Synthetic Hydrograph Development

To develop a synthetic hydrograph for flow at Pinehurst, a suitable long-term gauge needed to be selected for correlation. Data from the long-term gauge had to overlap existing data at Pinehurst (August 1987 to present) and extend back to the period of interest (1972 to 1987). Unfortunately, none of the SFCdA River gauging stations possess these characteristics (see Table 2 and Figure 4). Placer Creek, a major tributary to the SFCdA River located near Wallace, Idaho (Figure 1), has data available from October 30, 1967, to the present, except for one year from October 1, 1995, to September 30, 1996, when the gauge was offline. Figure 4 is a plot of the Kellogg Tunnel flows, Placer Creek flows, and SFCdA River flows for the various gauges.

The synthetic hydrograph for Pinehurst was created in three steps using the Placer Creek data and a commonly used regression method known as the REG method. The REG method exploits the correlation between flows at one site and concurrent flows at some nearby long-term gauge (Hirsch, 1982, and Vogel and Stedinger, 1985). With the REG method, a line of best fit is developed for the existing data using linear regression, and missing data values are estimated using the equation $y = mx + b$, where m and b are set to minimize error.

In the first step, the correlation between Placer Creek and SFCdA Pinehurst was evaluated for the period when both gauges were operational (August 12, 1987, through September 30, 1995, and October 1, 1996, through September 30, 1997). Pinehurst flow was plotted versus the Placer Creek flow using natural log and arithmetic scales, and linear regression was conducted to determine the line of best fit for the data. Figures 5 and 6 show how the lines of best fit calculated from both the natural log and arithmetic correlation fit the data points.

In the second step, the equation of the line of best fit for each plot was used to create synthetic Pinehurst data from Placer data. The synthetic data from both equations were compared to actual data using a hydrograph plot. Visual inspection of the hydrographs suggested the natural log correlation produced synthetic data that were reasonably close to the actual data, except during peak-flow events. The arithmetic correlation appeared to match actual peak flow conditions better than the natural log correlation. Therefore, a combination of the correlations was developed using the natural log relationship up to the point that the arithmetic line of best fit was crossed (peak-flow transition point shown in Figures 5 and 6), and the arithmetic relationship above that point. The resulting correlation is expressed as follows (units are gpm):

For Placer flow less than 39,511 gpm;

$$Pinehurst = e^{(0.7363 \times \ln(Placer) + 5.3299)}$$

For Placer flow above 39,511 gpm;

$$Pinehurst = 11.227 \times Placer + 56{,}801$$

Figure 7 provides a comparison of actual versus synthetic Pinehurst flow for the period that actual data are available. By comparing the actual versus synthetic plots, it can be seen that the predictive correlation does a good job of estimating actual river flows.

The third and last step involved using the developed correlation to estimate Pinehurst flow prior to August 1987. These estimated flows are combined with the measured flows after August 1987 as shown in Figure 8 to form the complete SFCdA River hydrograph at the Pinehurst gauge. Placer Creek and Kellogg Tunnel hydrographs are also shown in Figure 8 for comparison.

2.3.2 Possible Sources or Error for the Synthetic Pinehurst Flows

Development of synthetic flows for Pinehurst prior to August 1987 was necessary because there was no Pinehurst gauge prior to August 1987 and because TMDL compliance will be based on the Pinehurst gauge. Although the Figure 8 comparison between synthetic and actual Pinehurst flows shows a good ability to estimate actual flows using the mathematical approach described in Section 2.3.1, possible sources of error may impact the accuracy of the synthetic values.

One possible error source lies with the REG method, in that it is known to underestimate the variance of synthetic values (Hirsch, 1982. This may result in underestimating peak flow and overestimating low-flow values. Since TMDLs vary according to changes in flow at Pinehurst, there is a potential for the estimated TMDL to be lower than estimated during the summer months and higher than estimated during the winter months. However, inspection of Figure 8 shows that in general the low and high flows are being estimated well. Some of the estimated peak flows are higher than the actual, but others are lower.

Another possible source of error is related to the use of Placer Creek as the base gauging station to develop synthetic Pinehurst flows. The Placer Creek gauge measures flow from a 14.9-square-mile watershed over a limited elevation range with respect to the 299-square-mile Pinehurst watershed. Peak flows and low flows tend to be more extreme on a unit basis for small watersheds when compared to larger watersheds. Precipitation amount and type (snow or rain) varies dramatically with elevation. Additional basin characteristics that may vary between Placer Creek and Pinehurst include the amount of forested area, slope, orientation (north-south versus east-west), soil type, time of concentration (time required for the peak flow to reach the gauge), and storage capacity. These factors could affect the quality of the synthetic flow values that are developed for Pinehurst.

Regarding the record quality, the gauging station at Placer is situated below a water intake structure operated by the East Shoshone Water District. Placer Creek is one of four water sources for the district; others include Exhibition Draw, West Fork Draw, and Weyer Gulch Draw, with Placer and Exhibition draw being the two major sources. Average annual water withdrawal rates from all four sources are estimated to range from 1,000 to 1,200 gpm (Gulensoy personal communication, 1999). This rate increases to about 1,400 gpm during the summer months. An attempt was made to quantify the significance of this error by comparing the approximate withdrawal rates to the flow measured at the Placer gauge. Typical low-flow values at the gauge are in the range of 1,300 to 4,000 gpm, and higher flow values generally are between 4,000 and 16,000 gpm. Using these approximate values, the water withdrawn from Placer before it is measured at the gauge varies from 15 to 35 percent during the summer months, and 2 to 7 percent during other times of the year. This calculation suggests that the gauge is measuring 65 to 98 percent of the total flow coming from the watershed, depending on the time of year. Thus, there is the potential that the Pinehurst summer flows could be underestimated, although this is not apparent in Figure 8.

Although the above are possible sources of error to the development of the Synthetic Pinehurst flows, inspection of Figure 8 shows that the actual flows are being estimated well. Therefore, it is recommended that the synthetic Pinehurst flow values be used in subsequent TMDL compliance evaluations when estimates of SFCdA River flow at the Pinehurst gauge are needed prior to August 1987, when the Pinehurst gauge was established.

3.0 Hydrograph Comparison

This section compares the hydrographs developed for the Kellogg Tunnel and the Pinehurst gauge of the SFCdA River. These hydrographs are shown in Figure 8.

3.1 Comparative Basis

Because surface water inflow to the mine occurs as a result of snowmelt and precipitation over the hills above the mine, and because significant inflow is believed to occur where the West Fork Milo Creek intersects the Guy Caving Area, and where the Inez shaft intersects Deadwood Creek, the flow increase associated with snowmelt and precipitation should also be observed in the SFCdA River. The basis for comparing the Kellogg Tunnel and SFCdA River flows stems from the assumption that the relative increase in flows from the Kellogg Tunnel and in the river at the Pinehurst gauge are to some extent proportional.

However, it is also known that the nature of the flows from the Kellogg Tunnel is different from the SFCdA River because of historical mine operations, and because there are physical differences between Milo and Deadwood Creeks (the creeks that overlay portions of the mine workings) and the SFCdA River with respect to the basin elevations, slope, forest cover, precipitation, and area. Also, there is likely some delay as the snowmelt or precipitation travels from the surface through the ground and into the mine. Although these differences exist between KT flows and river flows, it is necessary to compare the hydrographs to determine the extent they impact the relationship between KT and river flow. This relationship was analyzed using four comparative approaches. Each of these approaches is described in the following subsections.

3.2 Kellogg Tunnel Versus SFCdA River at Pinehurst

The first approach involved a comparison of Kellogg Tunnel versus Pinehurst flows for each day of record. Flow versus flow curves were developed using linear scales and logarithmic scales. The plots were modified using various lag times to account for the possible difference in travel time into and through the mine compared to flow into the SFCdA River. Lag times of 0, 1, 2, 3, and 4 weeks were evaluated. Figure 9 presents a logarithmic (base 10) plot of Kellogg Tunnel versus SFCdA River flow with a zero lag time. This correlation was as good as any found using the different lag times and plot scales. As can be seen by the wide scatter, no clear correlation was found between Kellogg Tunnel and SFCdA River flows.

3.3 Kellogg Tunnel Versus Placer Creek

A second attempt to establish a correlation between Kellogg Tunnel and SFCdA was made using Kellogg Tunnel flow and Placer Creek flow data. Placer Creek is a tributary to SFCdA River that enters near Wallace, Idaho (Figure 1). It is situated along the south side of the valley facing north, similar to Milo Creek. Both linear and logarithmic plots were made of the data. Figure 10 is an example of an arithmetic plot. None of the plots showed a clear correlation between Kellogg Tunnel and Placer Creek flows.

3.4 9 Level Loadout Area Versus SFCdA River at Pinehurst and Placer Creek

The Kellogg Tunnel flows were evaluated in terms of the tunnel's tributary intra-mine flows. Underground monitoring locations were established in the 1980s by John Riley and others through the University of Idaho. These locations were restored during the 1998/1999 CH2M HILL mine water sampling program. One location, 9 Level Loadout Area (9LA), monitors flow that originates in the upper country workings, and thus receives most of its water via gravity drainage from surface water infiltration. This location was selected for analysis in an attempt to reduce the effect of mine operations on the historic data set since this flow is not affected by mine water pumping. A plot was developed for 9LA flow versus Pinehurst flow for the dates where these two sources overlap (February 10, 1983, through December 18, 1985). Data collected during the recent mine water sampling program was not included because Pinehurst data for this period is not yet available. Figure 11 shows this plot and suggests a slight correlation between 9LA flows in the mine and SFCdA River flows. Attempts to develop a line of best fit through the data resulted in an R^2 value of 0.457, which indicates a rather poor correlation. The evaluation of the data was also conducted using a logarithmic scale, but the results did not indicate a better correlation.

Finally, a similar plot of 9LA flows was plotted versus Placer Creek to determine if a relationship exists between these two flows. Data collected during the recent mine water monitoring program were not included in the plot because the Placer Creek data for this period are not yet available. This plot was similar to that shown in Figure 11, but had a slightly worse correlation coefficient ($R^2 = 0.413$).

3.5 Summary

The Kellogg Tunnel and SFCdA River flows do not correlate well. This is likely due to the following factors:

- Mining operations impacted the historic Kellogg Tunnel flows over time, with the result being little correlation to river flow. This could include operation of mine water pumping systems, inaccuracy of KT flow measurements at the portal Parshall flume resulting from either backwater from the downstream trash screen or muck building up in the flume itself, and sandfill water injection back into the mine.
- The SFCdA River receives flow from a large watershed (299 square miles) and is situated in the Silver Valley with both north-facing and south-facing slopes. The snow on the south-facing slopes generally melts sooner and faster than on the north-facing slopes because of sun exposure.
- Kellogg Tunnel flow consists of surface water inflow from Milo and Deadwood Creeks, groundwater inflow, and discharge from historic mining-related operations. Both Milo and Deadwood Creeks are small north-facing watersheds (less than one square mile), and only a portion of their flows leak into the mine.

- The elevation range of Milo and Deadwood Creeks is fairly limited versus the SFCdA River. Precipitation amounts and snowmelt events vary with elevation.
- Water recharge to the mine is a combination of infiltration from Milo and Deadwood Creeks, seepage through the overlying hillsides, and groundwater inflow. All these sources have different controlling mechanisms that are not well correlated with river flow.

Flow data for the Kellogg Tunnel versus Placer Creek, for 9LA versus the SFCdA River, and for 9LA versus Placer Creek, also do not exhibit a strong correlation. The relationship between 9LA and the SFCdA River exhibited the strongest correlation, but with an R^2 value of less than 0.5, which is rather poor; thus, the use of this correlation to approximate future flow scenarios for the Kellogg Tunnel is not recommended.

The analysis presented in this section between Kellogg Tunnel and SFCdA River flows shows there is not a good correlation between the historic flows. Therefore, it is not possible to predict Kellogg Tunnel flows using river flow, or vice versa. The development of the selection and design criteria for the treatment plant and overall mine water management system is therefore limited to using the historic flow record. Fortunately, the historic flow record is fairly substantial, spanning 27 years from 1972 to 1999, and contains a wide variety of flow extremes for both mine and river flows.

4.0 TMDL Compliance Evaluation Approach

This section describes the approach that will be used in subsequent evaluations to develop selection and design basis for the mine water management system. The approach uses the historic mine and river flow data to evaluate the ability of various hypothetical management systems to store and treat the mine water in compliance with the discharge requirements of the draft TMDL.

The major components of the mine water management system are:

- **Mitigations** to reduce water inflow to the mine—to reduce the outflow needing to be managed
- **Collection** of the mine water within the mine and discharge through the Kellogg Tunnel
- **Conveyance** of the mine water from the KT portal to the treatment plant
- **Storage** of the mine water prior to treatment
- **Treatment** of the mine water and discharge to Bunker Creek, which flows into the SFCdA River
- **Management** of the treatment residuals (sludge)

Each of these components is essential for mine water control, and thus selection and design of each must be done in concert with the others. For example, if mitigations that reduce mine inflow are constructed, then collection, conveyance, and storage of mine water is easier since there is less water. Plus, treatment to meet the TMDL requirements may be easier since there is less water to be discharged from the treatment plant. Also, depending on the effect of the mitigations on the mine water chemistry, the amount of sludge produced may change.

Because of the interrelationship of the components, their selection and design must consider the impact of any one on the others. Therefore, the evaluation approach needs to be flexible enough to allow this, plus flexible enough to allow analysis of many possible TMDL compliance scenarios. The latter refers to the fact that the TMDL is the major regulatory driver for developing the mine water management system. Any mine water management system must be evaluated for its ability to meet the TMDL requirements.

The complexity of the interrelationship of the mine water management components, combined with the requirement to meet the TMDL, requires development and use of a computer model that allows multiple "what if" scenarios to be played out. The historic mine flows could be artificially (via computer) run through different sizes and configurations of treatment plants, using different amounts of storage, and the discharge compared to the river flow and associated TMDL. Plus, hypothetical mitigations could be used to reduce the historic mine flows to check how these reduce the size of storage or treatment plant needed to meet the TMDL.

This type of computer model would be very useful for evaluating different mine water management strategies for TMDL compliance. Since the TMDL is a daily requirement, meaning that the amount of cadmium, lead, and zinc that can be discharged to Bunker Creek is to be determined daily based on river flow, the model should use daily historic mine and river flows. Although the period of historic KT flow data spans 27 years, not all of the years have sufficient data to allow daily modeling. Plus, even if they all did, 27 years of analysis would be cumbersome and require a major effort to both conduct and interpret. Therefore, what is needed is to select a smaller number of water years that have sufficient data to allow daily modeling, plus represent a wide variety of both mine and river flow conditions so the ability of the "what if" scenarios to meet the TMDL are better understood.

4.1 Selection of Water Years

Several years of Kellogg Tunnel flow data have been collected as described in Section 2.1. The selection of water years to use in the TMDL compliance modeling was done in three steps. First, statistical analysis was conducted to rank the water years according to peak and average flow years. Second, the data for each water year was reviewed to determine which water years contain sufficient data points to allow daily modeling. Third, the results of both of these steps were used to identify several water years that provide a range of peak and average flows to test for TMDL compliance over a wide range of possible mine and river flow conditions. These steps are described in more detail in the following subsections.

4.1.1 Statistical Analysis

Statistical analysis was conducted on a yearly basis to estimate the return interval of the peak and average flows for the Kellogg Tunnel historical data. This was done for each water year (October 1 through September 30). Peak and average SFCdA River flows and return intervals (Pinehurst gauge) for each of these years were compared to the peak and average KT flows to help select which KT years to use in the modeling. A two-parameter analysis was conducted to determine the return intervals. A return interval is the reciprocal of the probability of occurrence. For instance, a 25-year flow event for peak or average flows implies there is a 4 percent probability of peak or average flows of that magnitude occurring during any year.

4.1.1 Statistical Analysis

Statistical analysis was conducted on a yearly basis to estimate the return interval of the peak flows and average annual volumes for the Kellogg Tunnel historical data. This was done for each water year (October 1 through September 30). Peak and average SFCdA River flows and return intervals (Pinehurst gauge) for each of these years were compared to the peak and average KT flows to help select which KT years to use in the modeling. A three-parameter analysis (Log-Pearson Type III [LPIII]) was used to determine the return interval for peak flows and a two-parameter analysis (normal distribution) was used to determine the return interval for annual volumes. A return interval is the reciprocal of the probability of occurrence. For instance, a 25-year flow event for peak or average flows implies that there is a 4 percent probability of peak or average flows of that magnitude occurring during any year.

Statistics on peak flow data were determined using the maximum flow for the Kellogg Tunnel and Pinehurst within each water year. The maximum values were fitted using LPIII, an extreme event distribution. Two other methods (Generalized Extreme Value Distribution and Three-Parameter Log Normal Distribution) were also evaluated and no significant differences were observed in the resulting return frequencies. Therefore, the LPIII distribution was selected as the method of choice as specified in *Guidelines for Determining Flood Flow Frequency* (USGS, Bulletin 17B, 1982).

LPIII distribution relies on the calculated mean, standard deviation and co-variance of the data set. Three plotting positions were used for comparison – Gringorton, Weibull, and Blom Plotting Position. These plotting positions provided different ways to determine the frequency of occurrence. The results from each plotting position varied slightly, and the Blom Plotting Position was selected to represent peak return periods for both Kellogg Tunnel and Pinehurst because this method produces quantile unbiased flows for normally distributed data. The Blom Plotting Position for LPIII was also used in the preliminary statistical analysis performed for the draft report. The return frequencies and ranking of peak water years remained the same for Kellogg Tunnel flow compared to the draft report. However, results changed for Pinehurst peak flow year rankings and return frequencies, due to the refined synthetic Pinehurst flow data.

Annual flow volumes were also calculated for Kellogg Tunnel and Pinehurst for each water year. For those years without a complete daily Kellogg Tunnel flow record, annual flow volumes were calculated by averaging the available daily KT flows for each water year, and using this average to calculate the annul flow volume in gallons per year. The calculated annual flow volumes were fitted to a normal distribution because hydrologic flows may occur normally on an annual basis (Handbook of Hydrology, 1993). This distribution relies on the calculated mean and standard deviation parameters of the data set. The return period estimates are then extracted from the normal distribution.

The number of days of KT data available, and the return frequencies of the average annual flow (normal distribution) and the peak annual flow (LPIII Distribution) for Kellogg Tunnel and Pinehurst are summarized in Table 3 for water years 1968 (when Placer Creek data was first collected) through 1999. The data set and statistical calculation output are presented in Appendix A.

TABLE 3
Return Frequencies for Kellogg Tunnel and Pinehurst (years)

	Kellogg Tunnel			Pinehurst[a]	
Water Year	**Average**	**Peak**	**# Days KT Data Available**	**Average**	**Peak**
1968	-	-	0	2.1	1.3
1969	-	-	0	4.1	3.6
1970	-	-	0	1.8	1.7
1971	-	-	0	4.7	4.7
1972	-	-	0	8.6	3.2
1973[b]	**13.1**	**34.0**	**253**	**1.2**	**1.1**
1974	4.6	13.1	296	50.0	50.0
1975	3.2	1.2	3	1.9	2.5
1976	-	-	0	3.6	2.9
1977	-	-	0	1.0	1.0
1978	1.4	2.5	306	2.7	1.6
1979	2.8	3.8	322	1.3	6.8
1980	1.5	3.2	365	1.2	1.2
1981	**3.8**	**5.9**	**365**	**2.3**	**4.1**
1982	**34.0**	**8.1**	**354**	**3.3**	**11.9**
1983	1.8	2.0	364	2.9	1.4
1984	2.5	1.7	335	2.0	2.0
1985	8.1	1.5	10	1.6	1.9
1986	5.9	1.6	256	1.7	2.3
1987	**1.7**	**1.4**	**365**	**1.3**	**1.4**
1988	1.6	1.8	365	1.1	1.3
1989	2.0	2.8	347	1.5	1.5
1990	2.2	2.2	92	5.6	2.1
1991	-	-	0	6.8	5.6
1992	-	-	0	1.1	1.1
1993	-	-	0	1.4	1.8
1994	-		0	1.1	1.1
1995	1.0	1.0	76	2.5	2.7
1996	**1.1**	**4.6**	**234**	**11.9**	**19.2**
1997	1.3	1.3	73	19.2	8.6
1998	1.1	1.1	313	1.5	1.2
1999	1.2	1.1	317	-	-

Notes:
[a] Pinehurst data from 1968 through August 1987 is synthetic. The Pinehurst gauge became operational August 11, 1987.
[b] Water years in bold type were selected for modeling.
[c] KT flow data is available beginning December 1, 1972.

4.1.2 Water Year Selection

The information presented in Table 3 was used to select specific water years for the TMDL compliance modeling. A major criteria was that enough daily KT flow measurements were available in the water year to allow good representation of the daily flows for modeling. The Table 3 calculated return interval statistics for SFCdA River flow at Pinehurst were used to help assess whether the flow in the river for each year was relatively high or low. This is important for TMDL compliance because the most difficult compliance is when the mine water flows are high and the river flows are low; the easiest compliance is when the mine flows are low and the river flows are high. Therefore, it is desirable to select a wide range of possible mine/river flow conditions so that the "what if" compliance modeling scenarios are more rigorously tested.

A total of five water years were selected to represent a range of flow conditions: 1973, 1981, 1982, 1987, and 1996. A plot of Kellogg Tunnel and Pinehurst flows for each of these water years is presented in Figures 12, 13, 14, 15, and 16, respectively.

Water year 1973 (Figure 12) was selected because it contained the highest peak flow return interval of 34 years, and it had the second highest average flow return interval of 13.1 years. Pinehurst flows for this year were about average; therefore, this year represents a difficult TMDL compliance water year. This year only had 253 days of KT flow data available because the KT flow record begins on December 1, 1973.

Water year 1981 (Figure 13) was selected because both the KT and Pinehurst average and peak flow return intervals are moderately high. This year represents a moderately high flow year for TMDL compliance.

Water year 1982 (Figure 14) was selected because the average KT flow return interval is the highest on record. This water year could be a difficult one for TMDL compliance because the Pinehurst average flow was only moderately high.

Water year 1987 (Figure 15) was selected to represent an average to slightly higher than average flow year for both KT and SFCdA River at Pinehurst flows. This year had a full 365 days of KT data.

Water year 1996 (Figure 16) was selected because of the high average and peak SFCdA River at Pinehurst return interval values, and the relatively lower KT values. This year should be relatively easy for TMDL compliance.

5.0 Summary and Recommendations

The following summarizes the findings and recommendations presented in this report:

- There is not a good correlation between the historic Kellogg Tunnel flows and the SFCdA River flows at the Pinehurst gauge. It is therefore not possible to predict Kellogg Tunnel flows using river flow, or vice versa. Thus, development of selection and design criteria for the treatment plant and overall mine water management system is limited to using the historic flow record.
- The complexity of the interrelationship of the mine water management components, combined with the requirement to meet the TMDL, requires development and use of a computer model that allows multiple "what if" scenarios to be evaluated. The historic mine water flows should be artificially (via computer) run through different sizes and configurations of treatment plants, using different amounts of storage, and the discharge compared to the river flow and associated TMDL. Plus, hypothetical mitigations should be used to reduce the historic mine flows to check how these reduce the size of storage or treatment plant needed to meet the TMDL.
- Since the TMDL is a daily requirement, the model should use daily historic mine and river flows.
- A total of five water years were selected to represent a range of flow conditions for the modeling: 1973, 1981, 1982, 1987, and 1996.

6.0 References

CH2M HILL. 1999a. *Analysis of Bunker Hill Mine Pool and South Fork Coeur d'Alene River Hydraulic Relationships Technical Memorandum*. May 5, 1999.

__________. 1999b. *Acid Mine Drainage—Bunker Hill Mine Water Conceptual Model*. July 1999.

__________. 1999c. *Bunker Hill Mine Water Presumptive Remedy*. July 1999.

Erikson, Daniel L. 1985. *Analysis of Water Movement in an Underground Lead-Zinc Mine, Coeur d'Alene Mining District, Idaho*. Unpublished Master's thesis. University of Idaho. May 1985.

Gulensoy, Nahide. 1999. Personal communication with Carl at the East Shoshone Water District. October 15 and 26, 1999.

Hirsch, Robert M. 1982. *Comparison of Four Streamflow Record Extension Techniques*. Water Resources Research. Volume 18, Number 4. Pp. 1081-1088. August 1982.

Maidment, David R. 1993. *Handbook of Hydrology*. McGraw-Hill. 1993

Riley, John A. 1990. *A Comparison of Multivariate Statistical Analysis and the Use of an Indicator Ion for the Interpretation of Water Quality Data*. Unpublished dissertation. University of Idaho. June 1990.

Trexler, Bryson D., Jr. 1975. *The Hydrogeology of Acid Production in a Lead-Zinc Mine*. Dissertation. University of Idaho. June 1975.

U.S. Environmental Protection Agency (EPA). 1999. *Draft Total Maximum Daily Load for Dissolved Cadmium, Dissolved Lead, and Dissolved Zinc in Surface Waters of the Coeur d'Alene Basin*. U.S. Environmental Protection Agency, Region 10. April 1999.

U.S. Geological Survey (USGS). http://waterdata.usgs.gov/nwis-w/ID.

USGS. 1982. *Guidelines for Determining Flood Flow Frequency*. USGS Bulletin 17B. 1982.

Vogel, Richard M. and Jerry R. Stedinger. 1985. *Minimum Variance Streamflow Record Augmentation Procedures*. Water Resources Research. Volume 21, Number 5. Pp. 715-723. May 1985.

Figures

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Figure 1
Bunker Hill Mine and South Fork Coeur D'Alene River
Vicinity Map

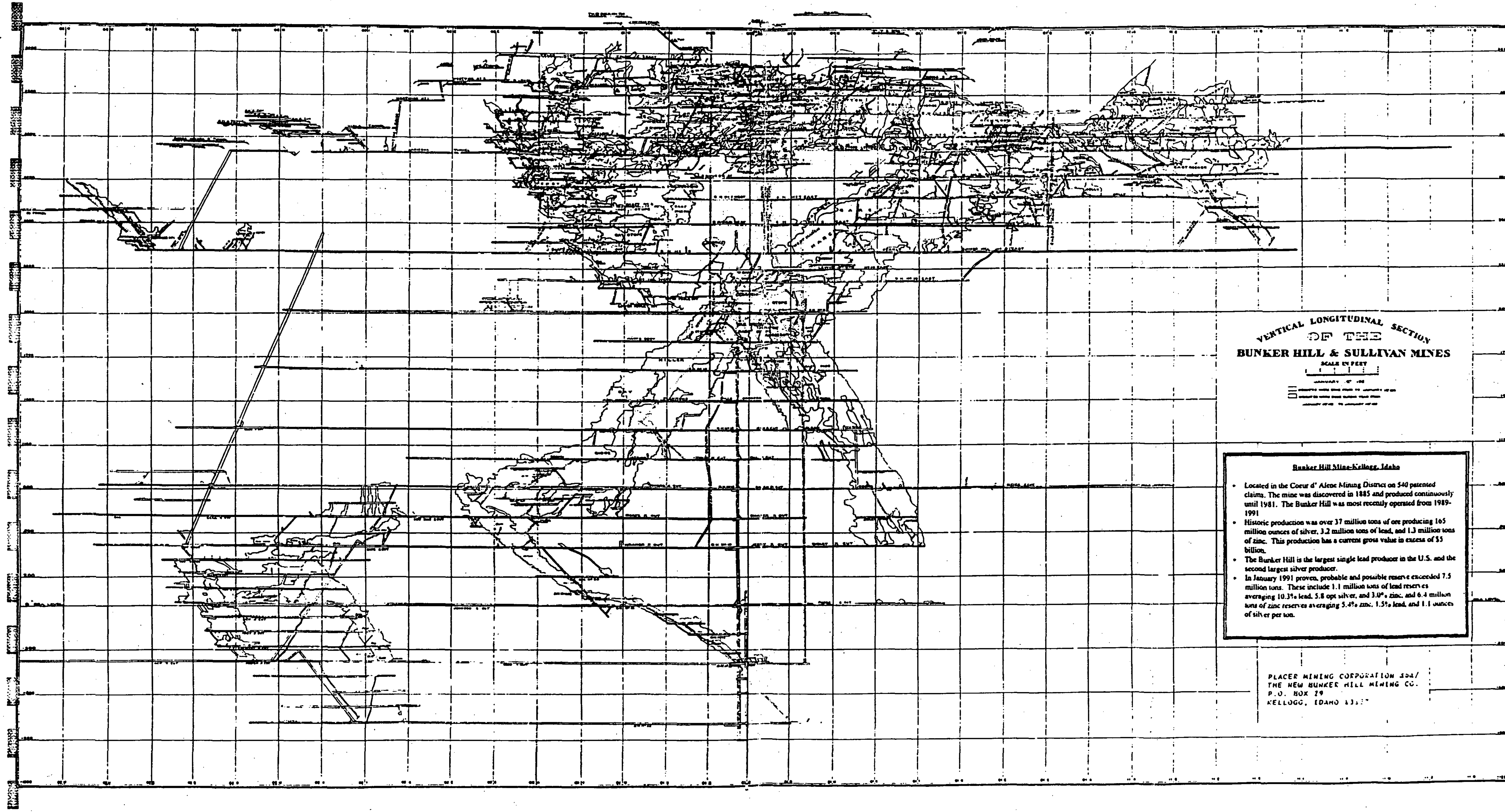

FIGURE 2
CROSS SECTIONAL VIEW OF THE MINE

FIGURE 3
All Kellogg Tunnel Flow Data Reviewed for Possible Use in Developing the Kellogg Tunnel Hydrographs

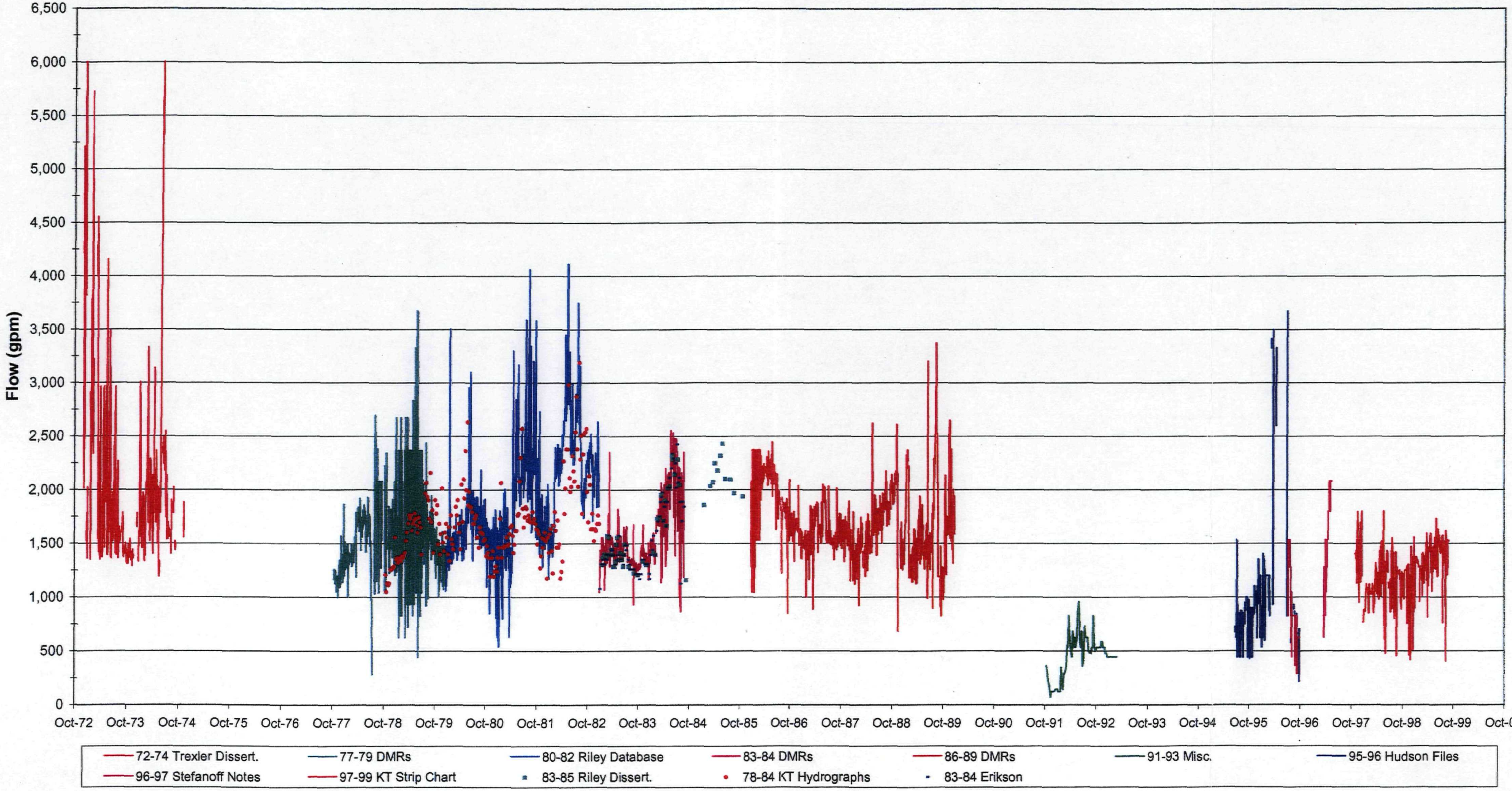

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FIGURE 4
Kellogg Tunnel, South Fork Coeur d'Alene River, and Placer Creek Hydrographs (1966-1999)

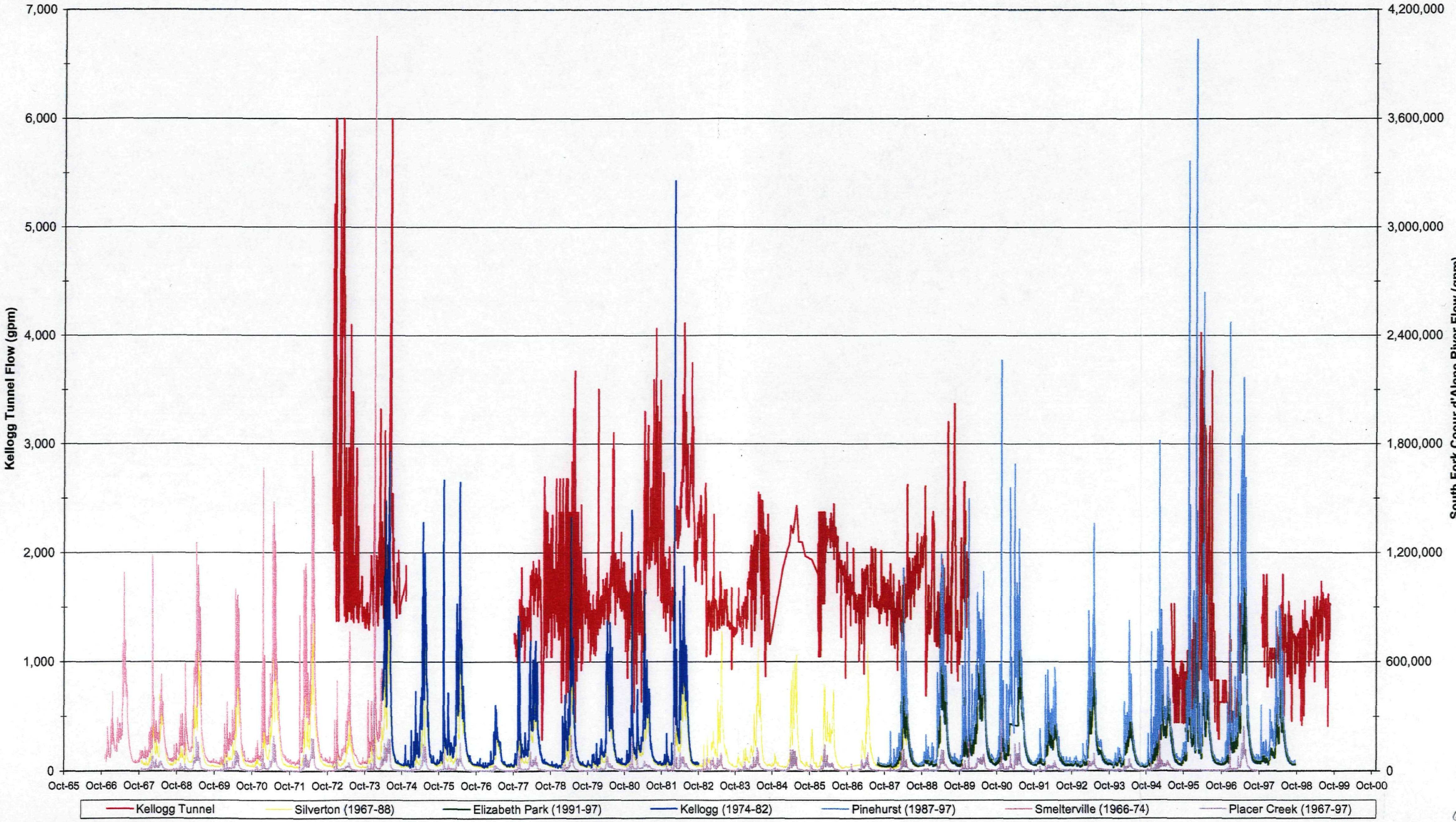

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FIGURE 5
ln Pinehurst Flow vs ln Placer Creek Flow
(both natural log and arithmetic correlations are shown)

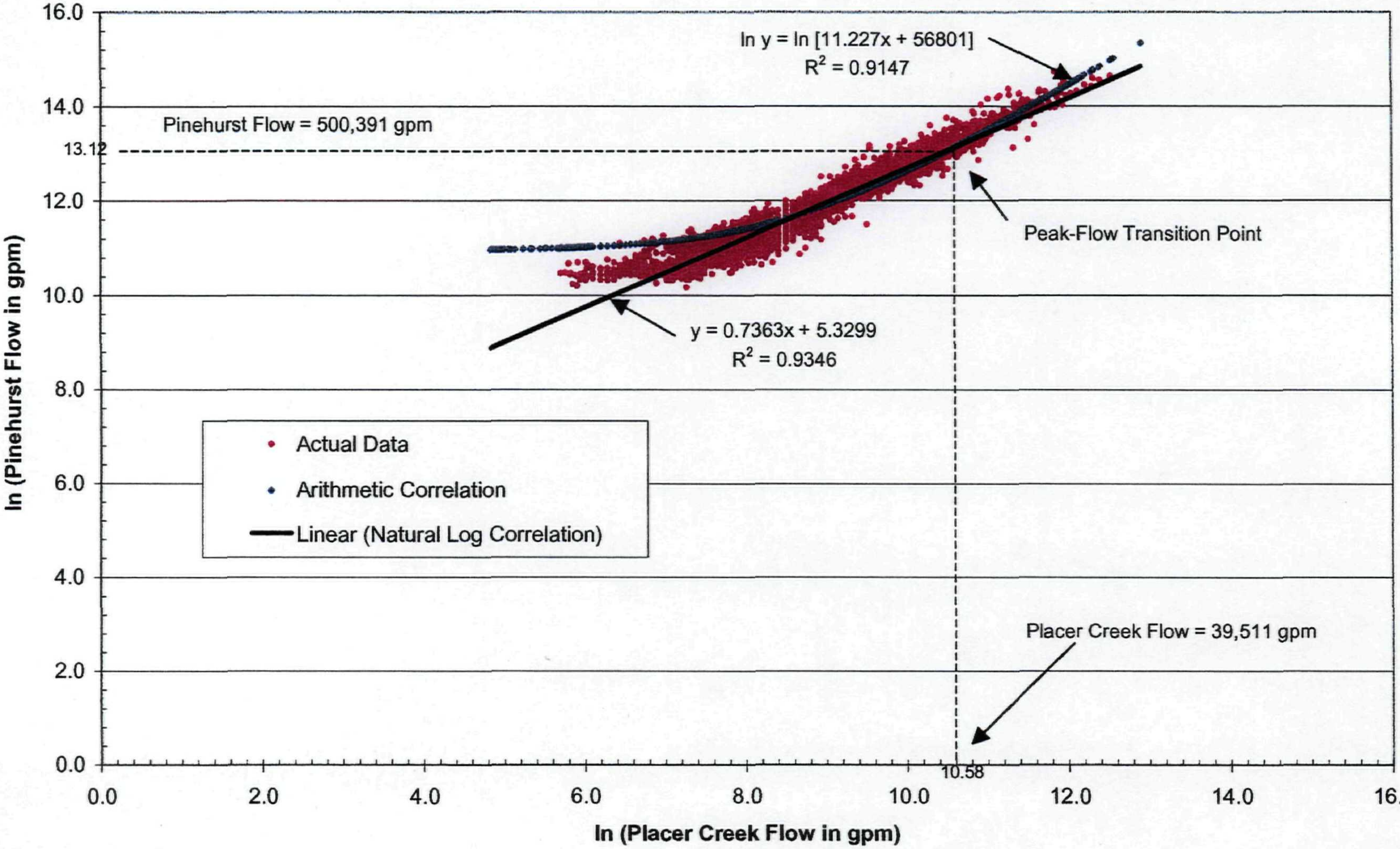

FIGURE 6
Pinehurst Flow vs Placer Creek Flow (Arithmetic Scales)
(both natural log and arithmetic correlations are shown)

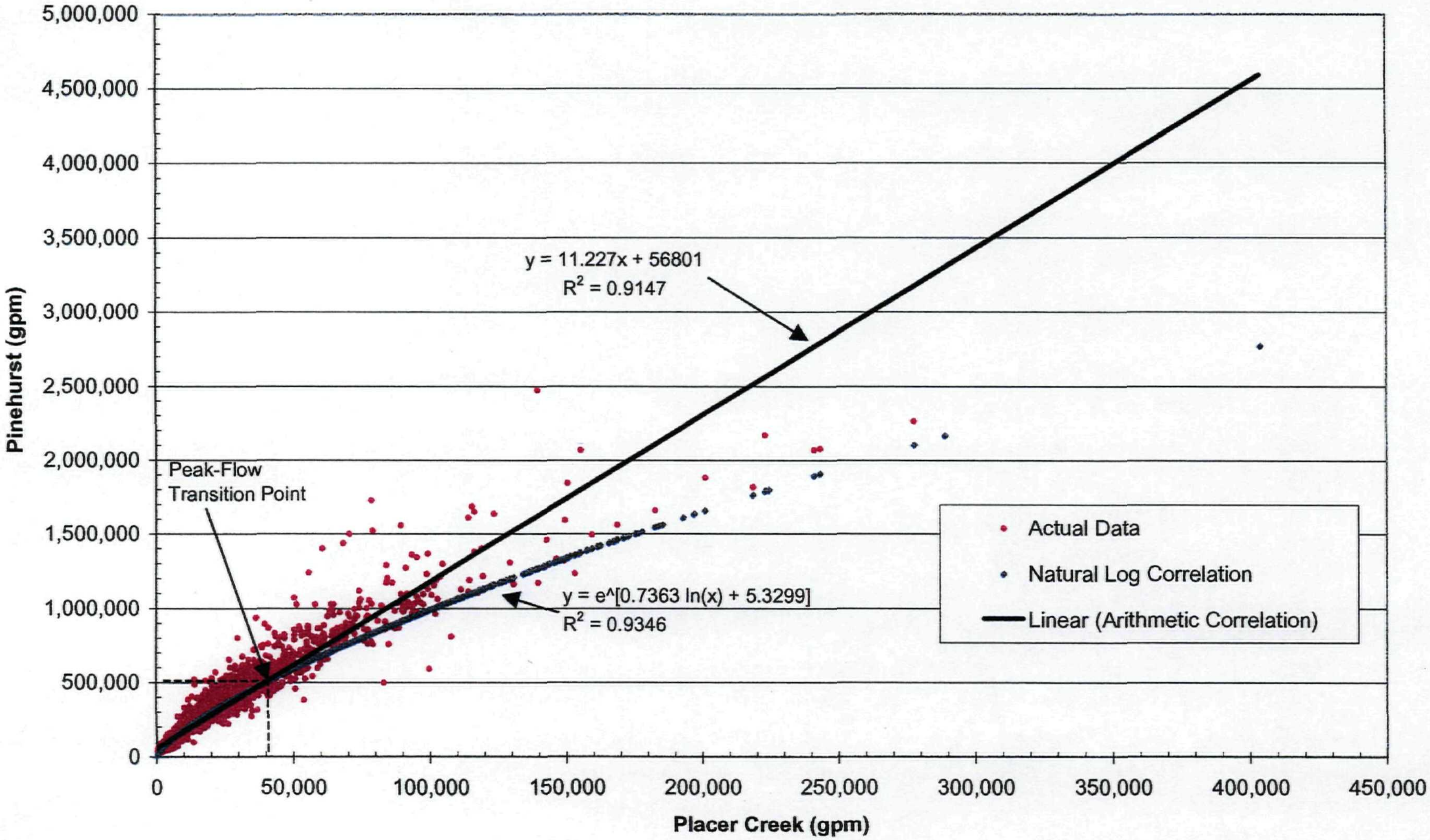

FIGURE 7
Comparison of Actual Pinehurst, Synthetic Pinehurst, and Placer Creek Flows

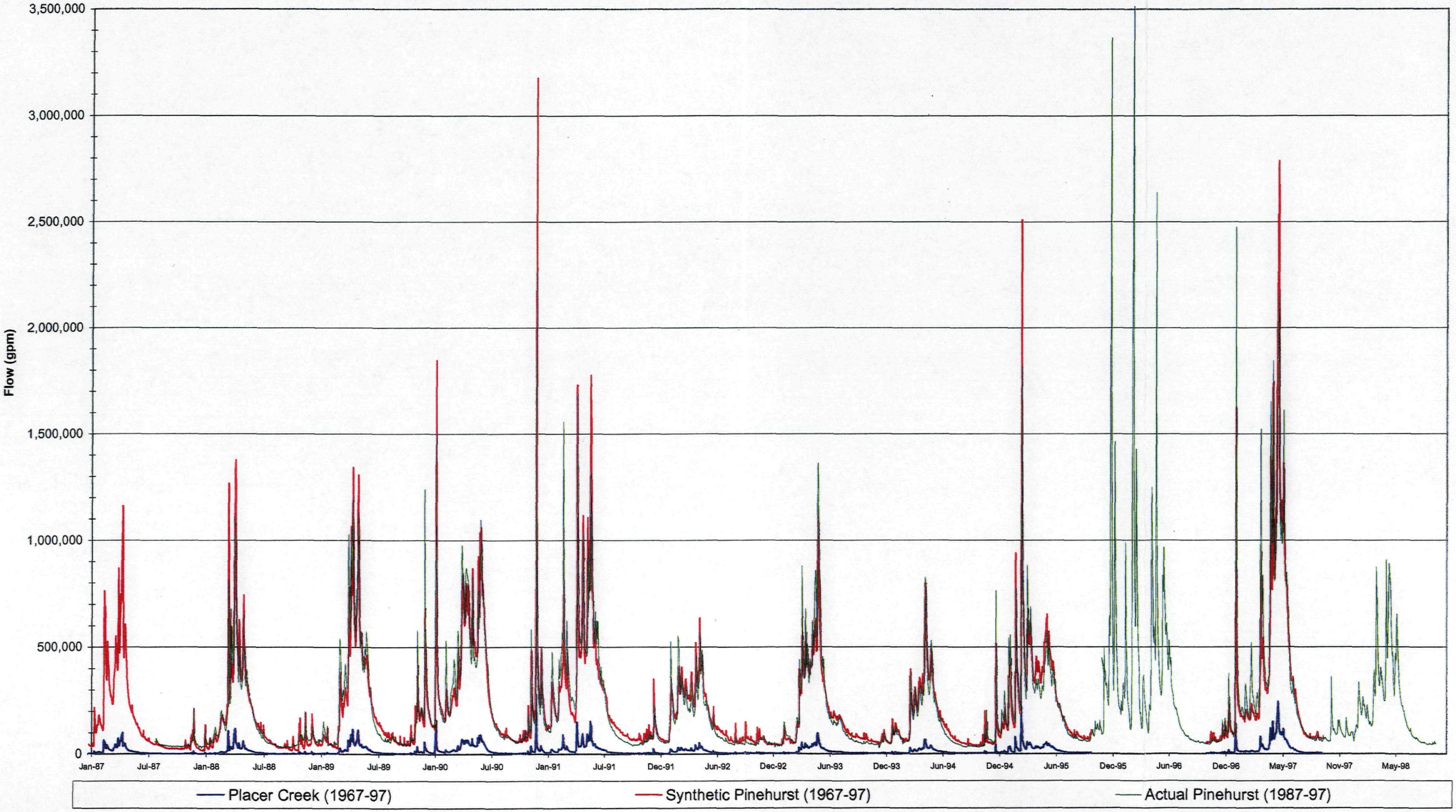

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FIGURE 8
Kellogg Tunnel, Synthetic (Pre 8/87) and Actual (Post 8/87) Pinehurst, and Placer Creek Hydrographs

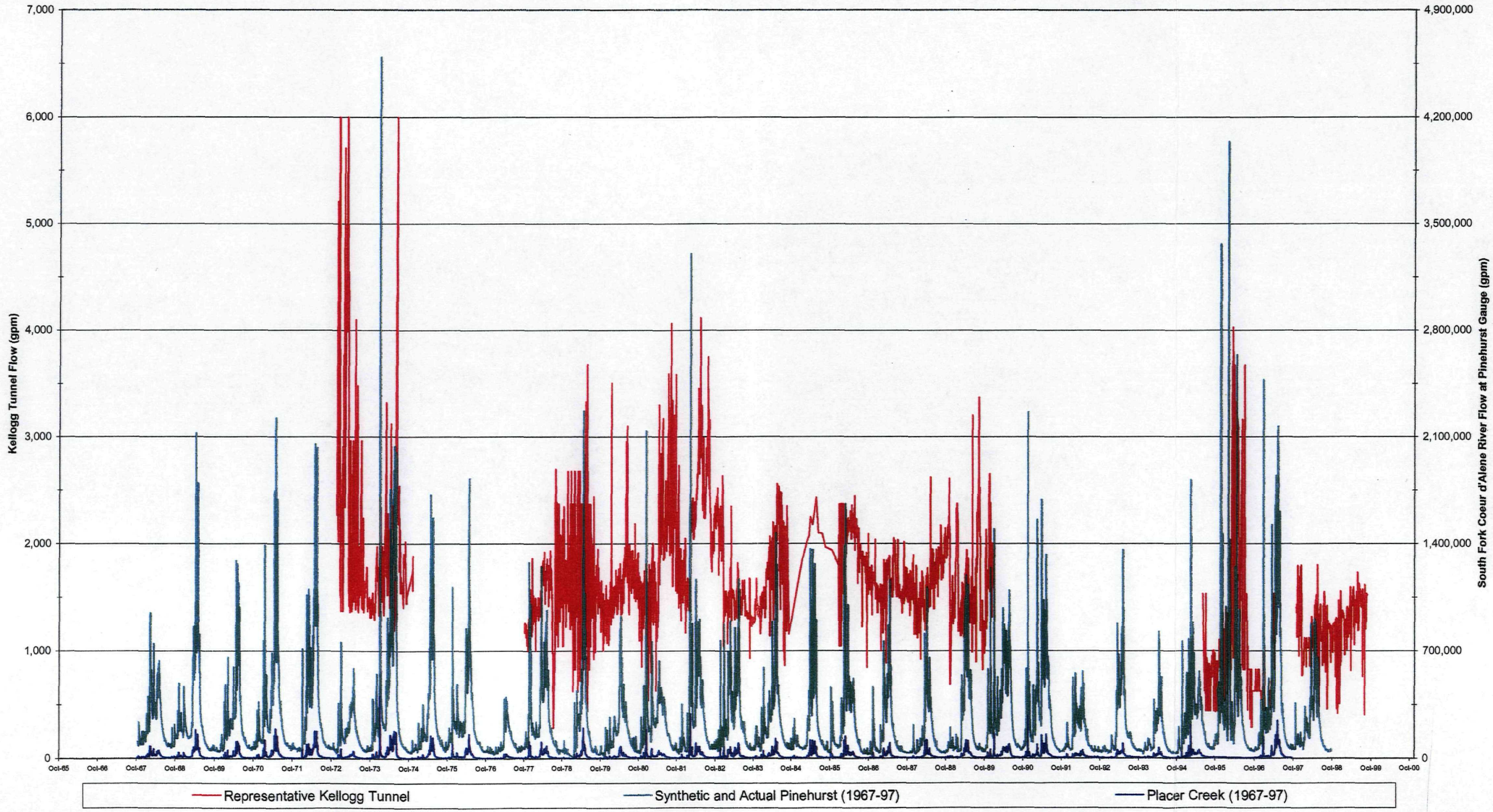

FIGURE 9
Log-Log Comparison of Kellogg Tunnel (1977-99) vs Pinehurst (1967-98)
(Zero Lag Time Between KT and River Flows)

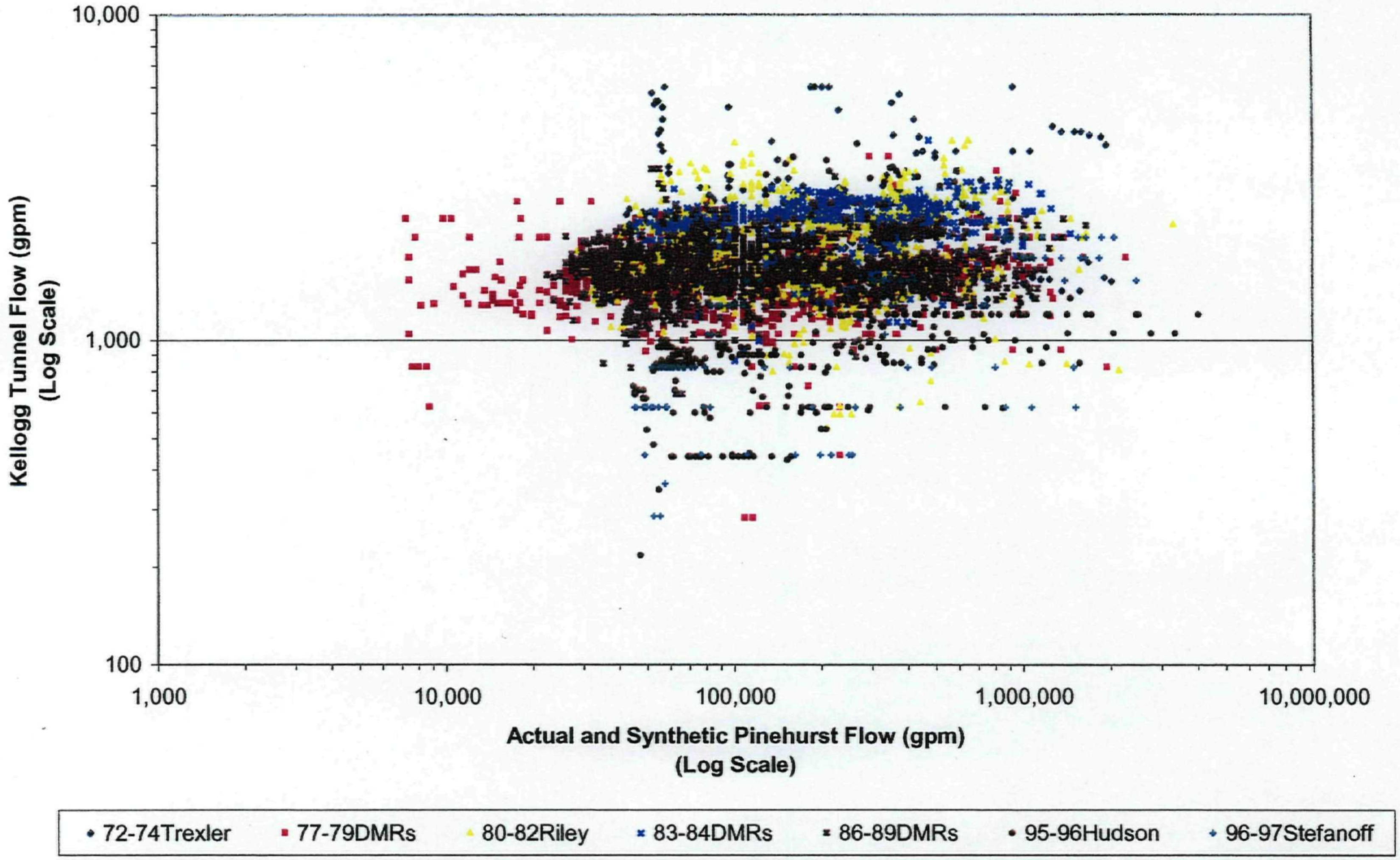

FIGURE 10
Kellogg Tunnel Flow vs Placer Creek Flow
(Overlapping Data Period is between 12/1/72 and 9/30/97)

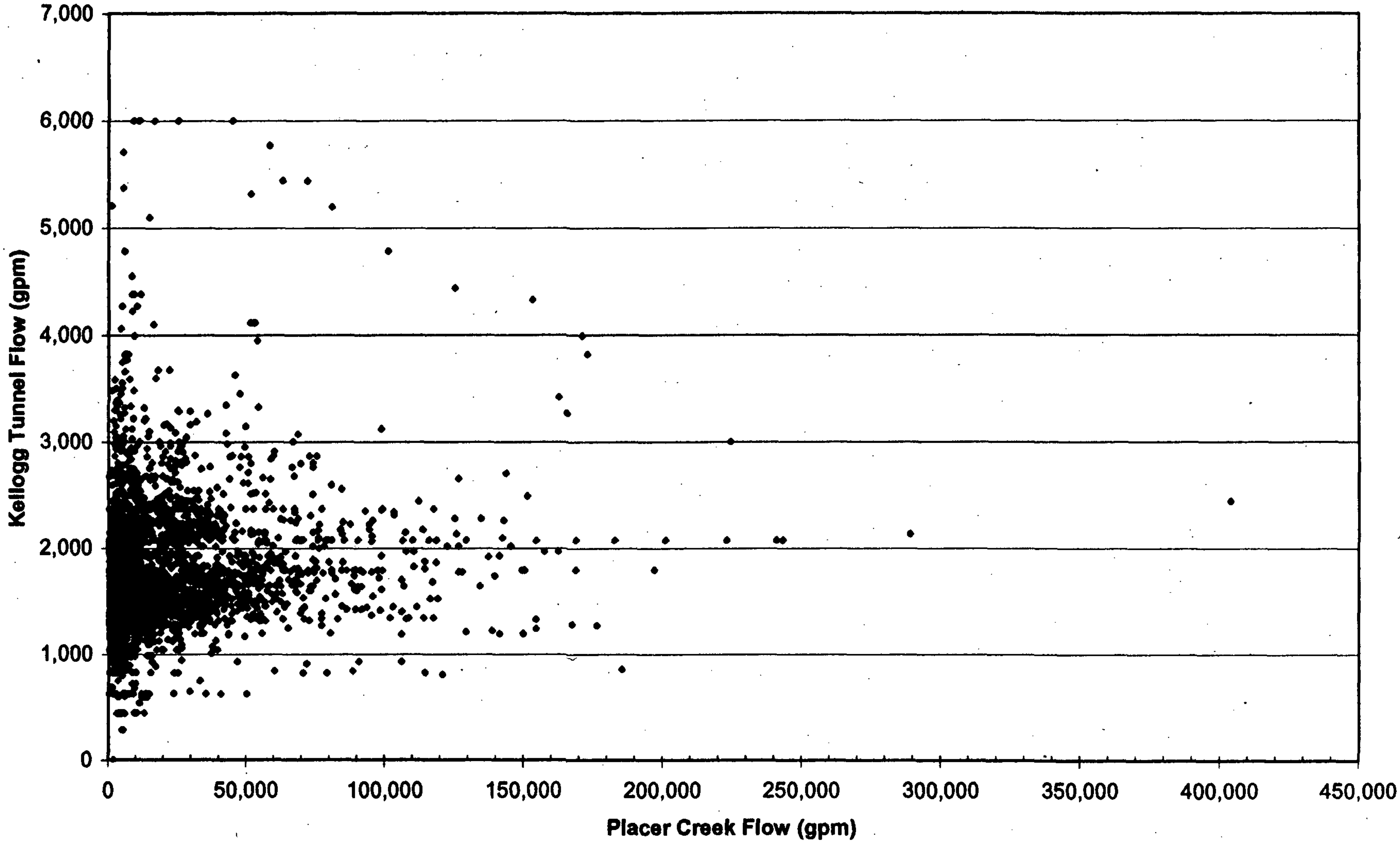

FIGURE 11
9 Level Loadout Area Flow vs Synthetic Pinehurst Flow

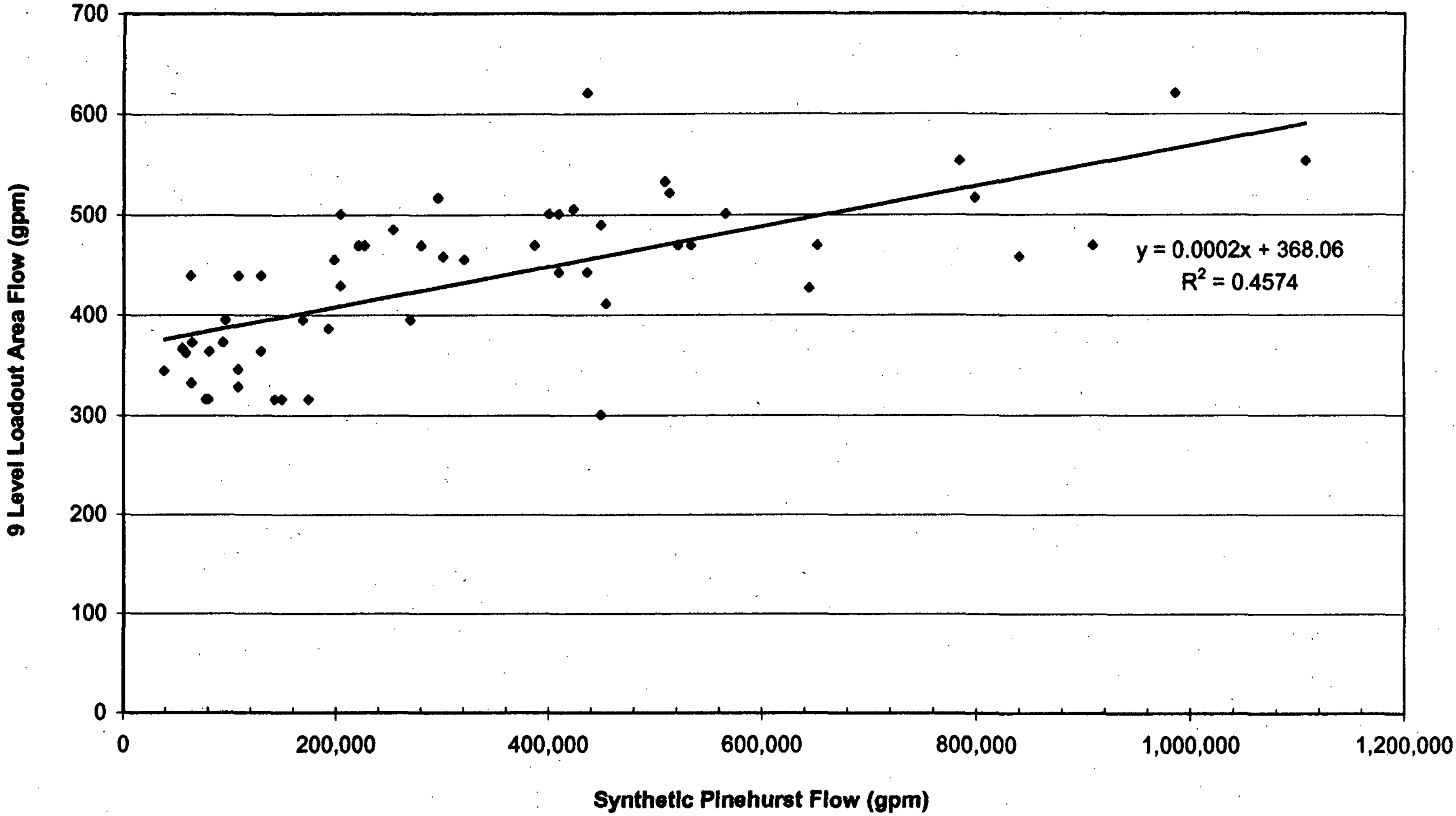

FIGURE 12
Kellogg Tunnel Flow vs Synthetic SFCdA River Flow at Pinehurst
Water Year 1973

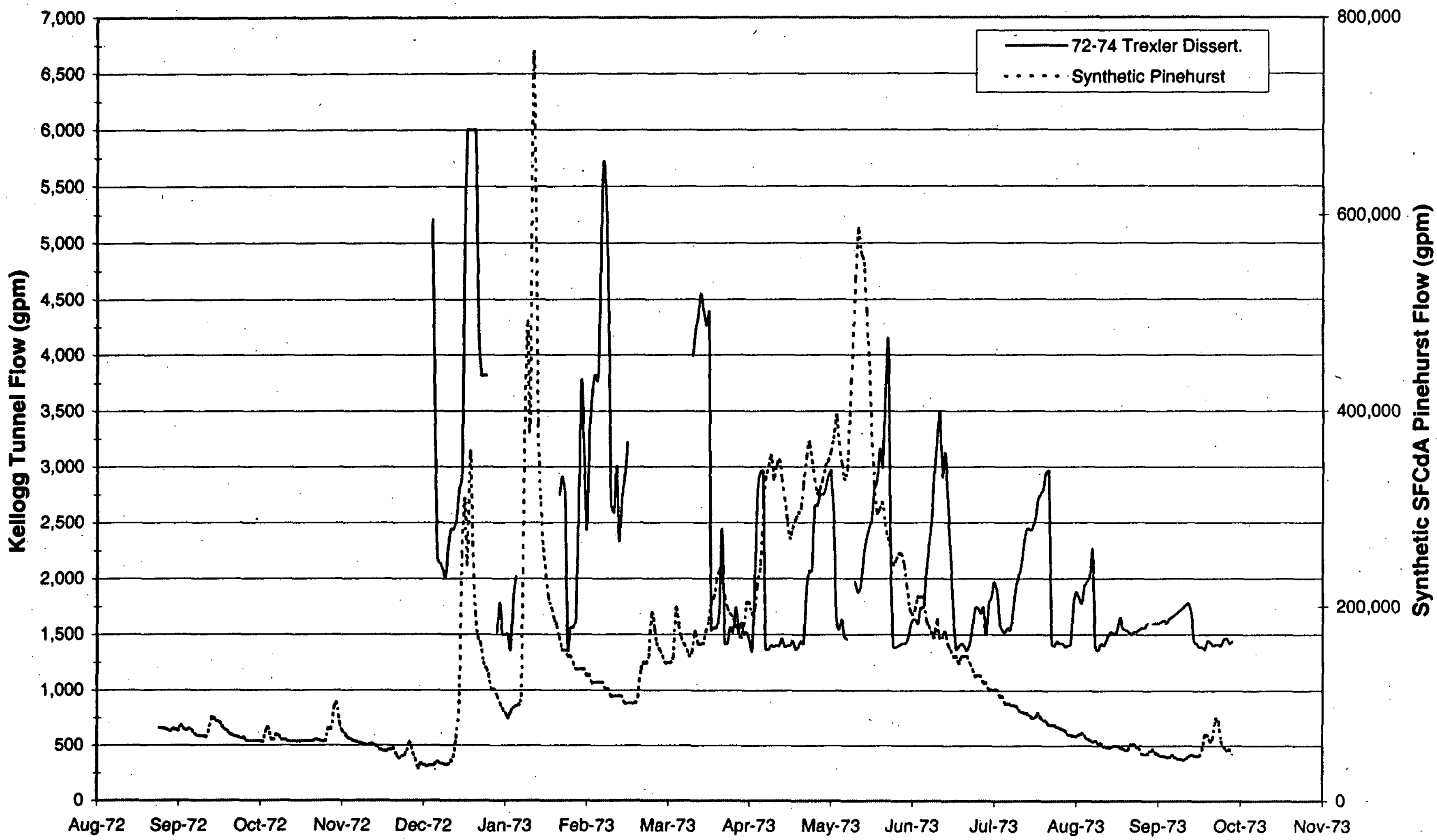

FIGURE 13
Kellogg Tunnel Flow vs Synthetic SFCdA River Flow at Pinehurst
Water Year 1981

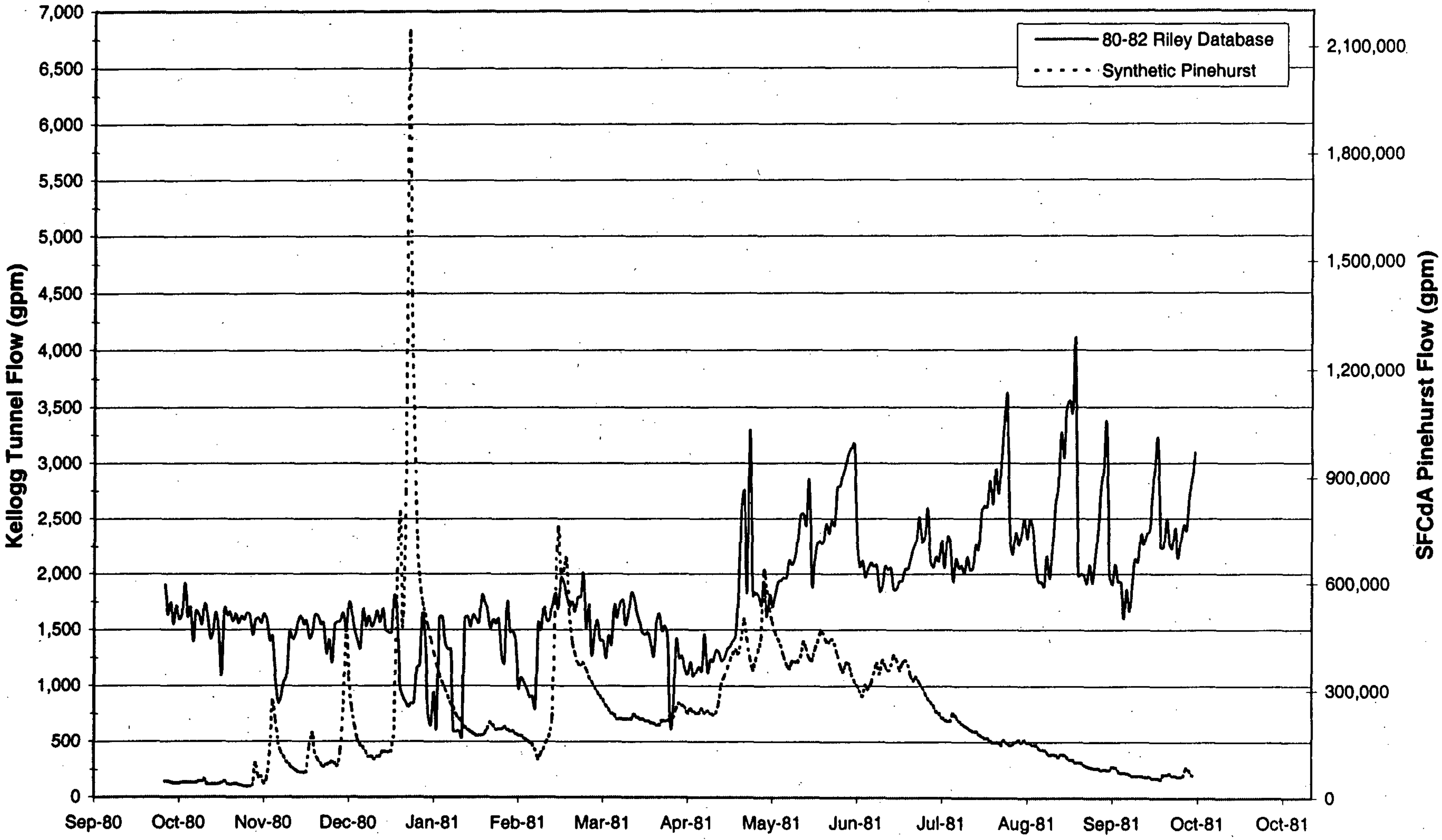

FIGURE 14
Kellogg Tunnel Flow vs Synthetic SFCdA River Flow at Pinehurst
Water Year 1982

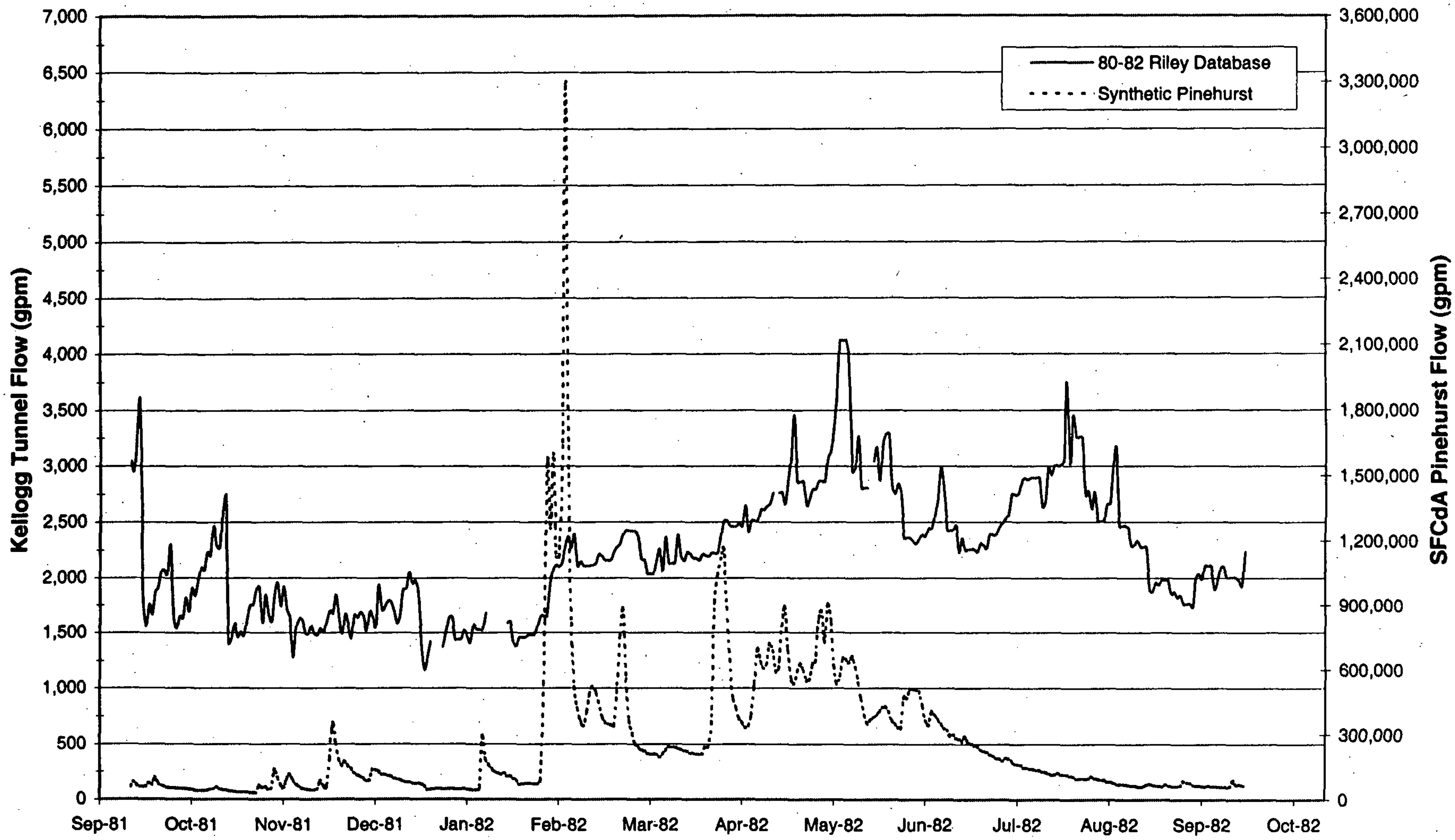

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FIGURE 15
Kellogg Tunnel Flow vs Synthetic SFCdA River Flow at Pinehurst
Water Year 1987

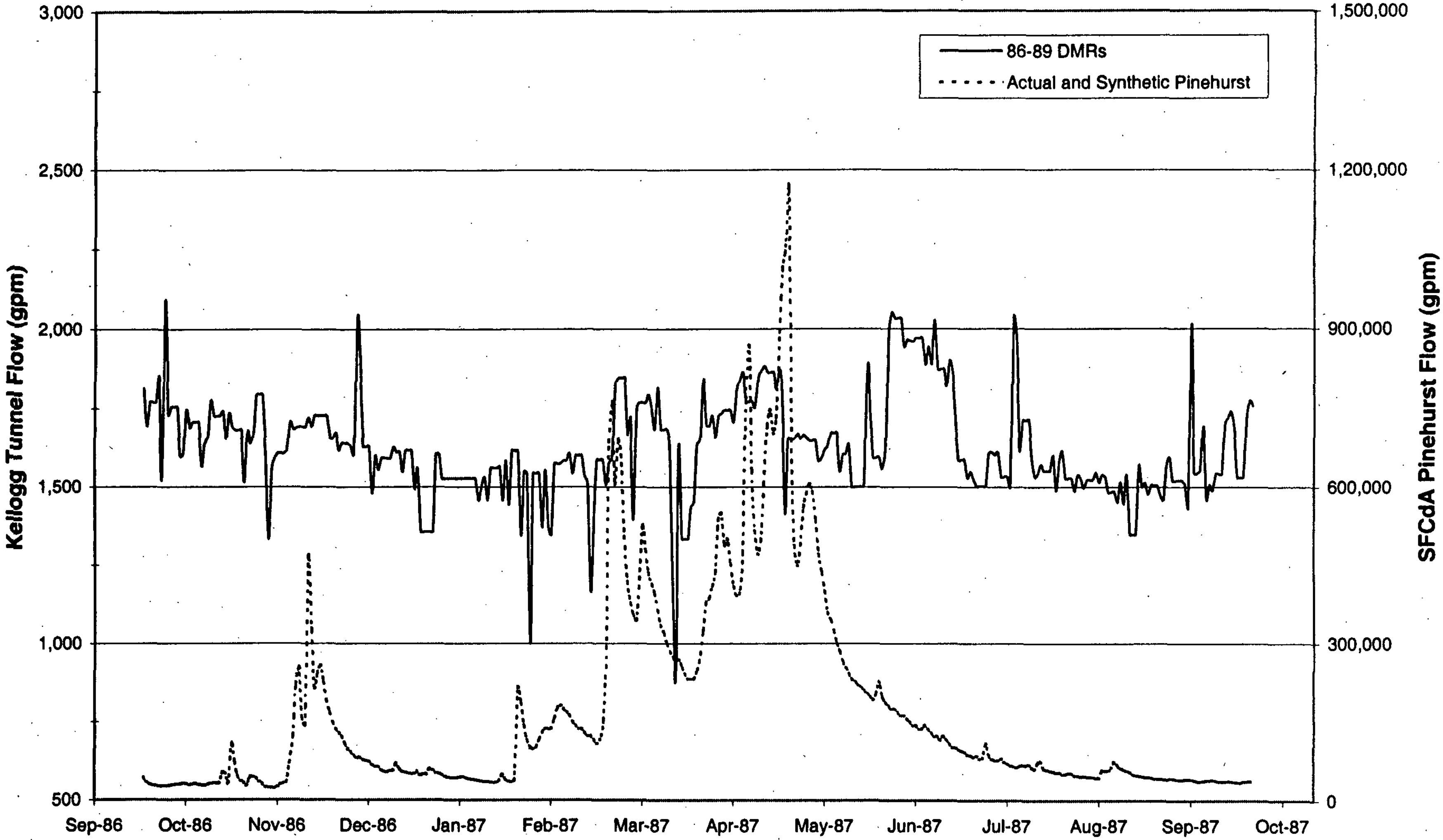

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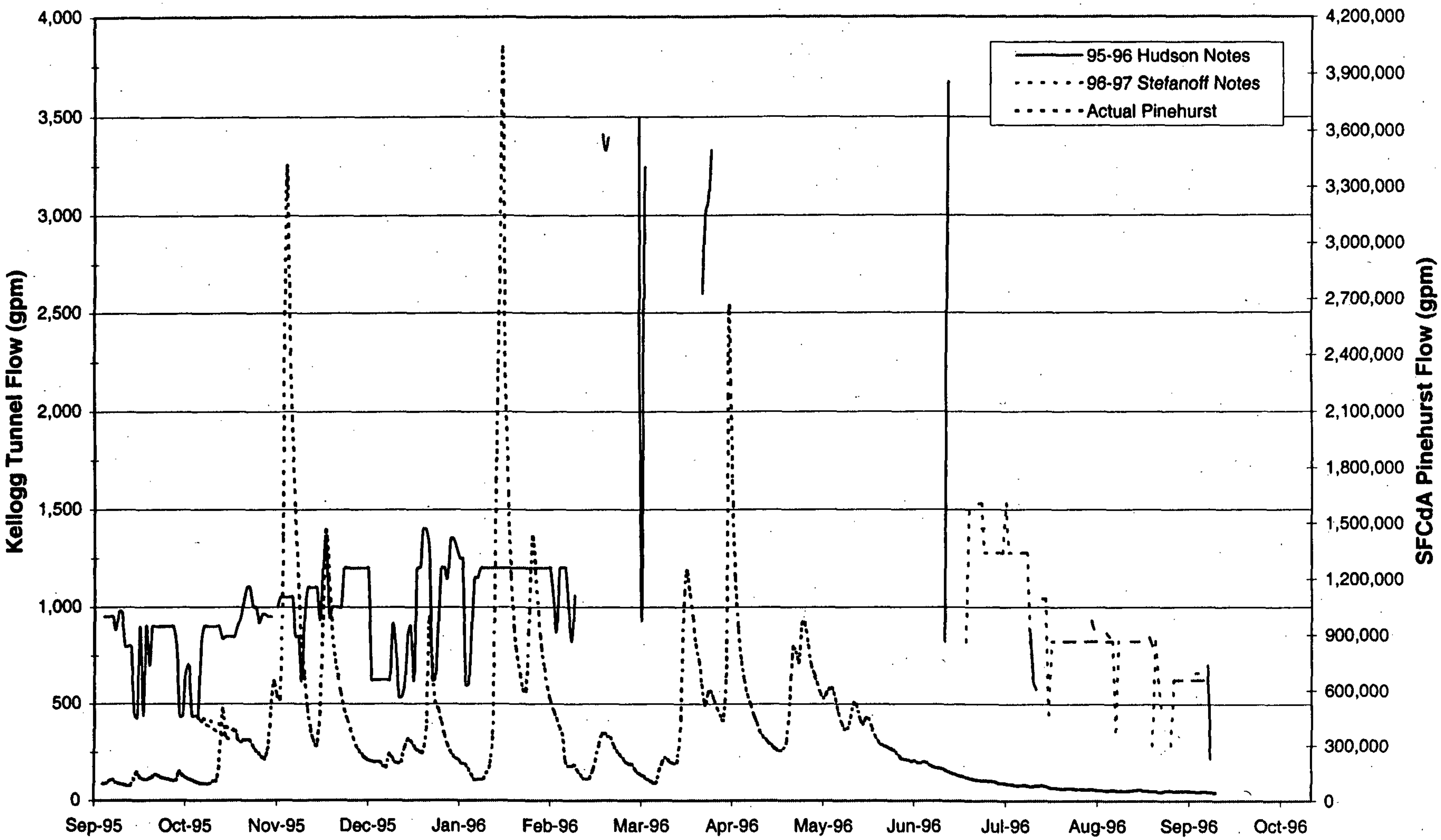
FIGURE 16
Kellogg Tunnel Flow vs SFCdA River Flow at Pinehurst
Water Year 1996



Appendix

Statistical Analysis

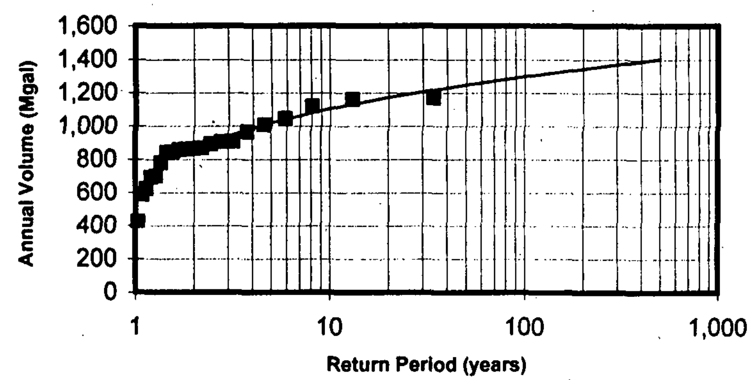
Bunker Hill Hydrologic Analysis

STATION: **Kellogg Tunnel**
PARAMETER : **Average Annual Volume**
NORMAL DISTRIBUTION

Average	862.0		Plotting Position
Std dev	187.3		Blom (1958)
Count	21		(M-3/8)/(N+1/4)
CV	0.217		N=number of items

Year	Annual Volume (Mgal)	Sorted Volume Year	Sorted Volumes (Mgal)	Rank	Plotting Position (Prob)	Return Period (years)
1973	1,158.4	1982	1,167.7	1	0.0294	34.00
1974	1,006.2	1973	1,158.4	2	0.0765	13.08
1975	907.5	1985	1,118.4	3	0.1235	8.10
1978	778.5	1986	1,044.9	4	0.1706	5.86
1979	904.8	1974	1,006.2	5	0.2176	4.59
1980	841.1	1981	962.3	6	0.2647	3.78
1981	962.3	1975	907.5	7	0.3118	3.21
1982	1,167.7	1979	904.8	8	0.3588	2.79
1983	861.2	1984	890.9	9	0.4059	2.46
1984	890.9	1990	868.2	10	0.4529	2.21
1985	1,118.4	1989	864.1	11	0.5000	2.00
1986	1,044.9	1983	861.2	12	0.5471	1.83
1987	856.0	1987	856.0	13	0.5941	1.68
1988	842.4	1988	842.4	14	0.6412	1.56
1989	864.1	1980	841.1	15	0.6882	1.45
1990	868.2	1978	778.5	16	0.7353	1.36
1995	425.9	1997	699.9	17	0.7824	1.28
1996	587.5	1999	691.9	18	0.8294	1.21
1997	699.9	1998	623.5	19	0.8765	1.14
1998	623.5	1996	587.5	20	0.9235	1.08
1999	691.9	1995	425.9	21	0.9706	1.03

Return Period (years)	Probability	K Value	Estimated Value (Mgal)
2	0.5000	0.000	862
2.33	0.4292	0.178	895
5	0.2000	0.841	1,020
10	0.1000	1.282	1,102
20	0.0500	1.645	1,170
50	0.0200	2.054	1,247
100	0.0100	2.327	1,298
200	0.0050	2.576	1,345
500	0.0020	2.879	1,401

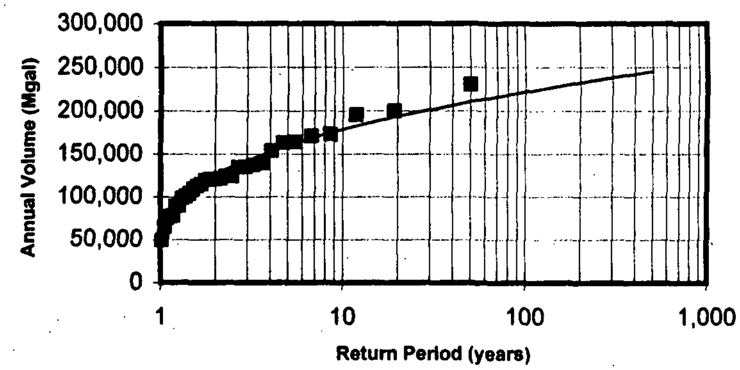


STATION: **Pinehurst**
PARAMETER : **Average Annual Volume**
NORMAL DISTRIBUTION

Average	125,091		Plotting Position
Std dev	41,472		Blom (1958)
Count	31		(M-3/8)/(N+1/4)
CV	0.332		N=number of items

Year	Annual Volume (Mgal)	Sorted Volume Year	Sorted Volumes (Mgal)	Rank	Plotting Position (Prob)	Return Period (years)
1968	120,975	1974	230,017	1	0.0200	50.00
1969	153,280	1997	199,606	2	0.0520	19.23
1970	118,772	1996	195,376	3	0.0840	11.90
1971	162,879	1972	172,877	4	0.1160	8.62
1972	172,877	1991	170,529	5	0.1480	6.76
1973	77,726	1990	163,830	6	0.1800	5.56
1974	230,017	1971	162,879	7	0.2120	4.72
1975	119,693	1969	153,280	8	0.2440	4.10
1976	138,627	1976	138,627	9	0.2760	3.62
1977	49,247	1982	136,861	10	0.3080	3.25
1978	134,280	1983	134,620	11	0.3400	2.94
1979	98,136	1978	134,280	12	0.3720	2.69
1980	88,750	1995	123,799	13	0.4040	2.48
1981	123,274	1981	123,274	14	0.4360	2.29
1982	136,861	1968	120,975	15	0.4680	2.14
1983	134,620	1984	120,192	16	0.5000	2.00
1984	120,192	1975	119,693	17	0.5320	1.88
1985	112,268	1970	118,772	18	0.5640	1.77
1986	113,955	1986	113,955	19	0.5960	1.68
1987	89,310	1985	112,268	20	0.6280	1.59
1988	76,830	1989	108,399	21	0.6600	1.52
1989	108,399	1998	103,204	22	0.6920	1.45
1990	163,830	1993	100,413	23	0.7240	1.38
1991	170,529	1979	98,136	24	0.7560	1.32
1992	74,830	1987	89,310	25	0.7880	1.27
1993	100,413	1980	88,750	26	0.8200	1.22
1994	65,272	1973	77,726	27	0.8520	1.17
1995	123,799	1988	76,830	28	0.8840	1.13
1996	195,376	1992	74,830	29	0.9160	1.09
1997	199,606	1994	65,272	30	0.9480	1.05
1998	103,204	1977	49,247	31	0.9800	1.02

Return Period (years)	Probability	K Value	Estimated Value (Mgal)
2	0.5000	0.000	125,091
2.33	0.4292	0.178	132,477
5	0.2000	0.841	159,988
10	0.1000	1.282	178,247
20	0.0500	1.645	193,321
50	0.0200	2.054	210,282
100	0.0100	2.327	221,587
200	0.0050	2.576	231,932
500	0.0020	2.879	244,468



Bunker Hill Mine Water Management
KELLOGG TUNNEL - Peak Flow Log Pearson Type III Distribution

Log Pearson Type III

Return Period	Probobility	K Value	Peak Discharge		
1.0101	0.99	-1.912	1339	-1.88	-2.029
1.25	0.8	-0.857	2029	-0.857	-0.855
2	0.5	-0.092	2742	-0.099	-0.066
5	0.2	0.803	3901	0.8	0.816
10	0.1	1.326	4792	1.328	1.317
25	0.04	1.926	6071	1.939	1.88
50	0.02	2.338	7140	2.359	2.261
100	0.01	2.725	8316	2.755	2.615

Reg/ Weight Skew	K Value	Peak Q	DeltaQ
0.2	-2.178	1206	133
0.2	-0.850	2035	-5
0.2	-0.033	2807	-64
0.2	0.830	3943	-41
0.2	1.301	4746	46
0.2	1.818	5818	254
0.2	2.159	6654	486
0.2	2.472	7526	789

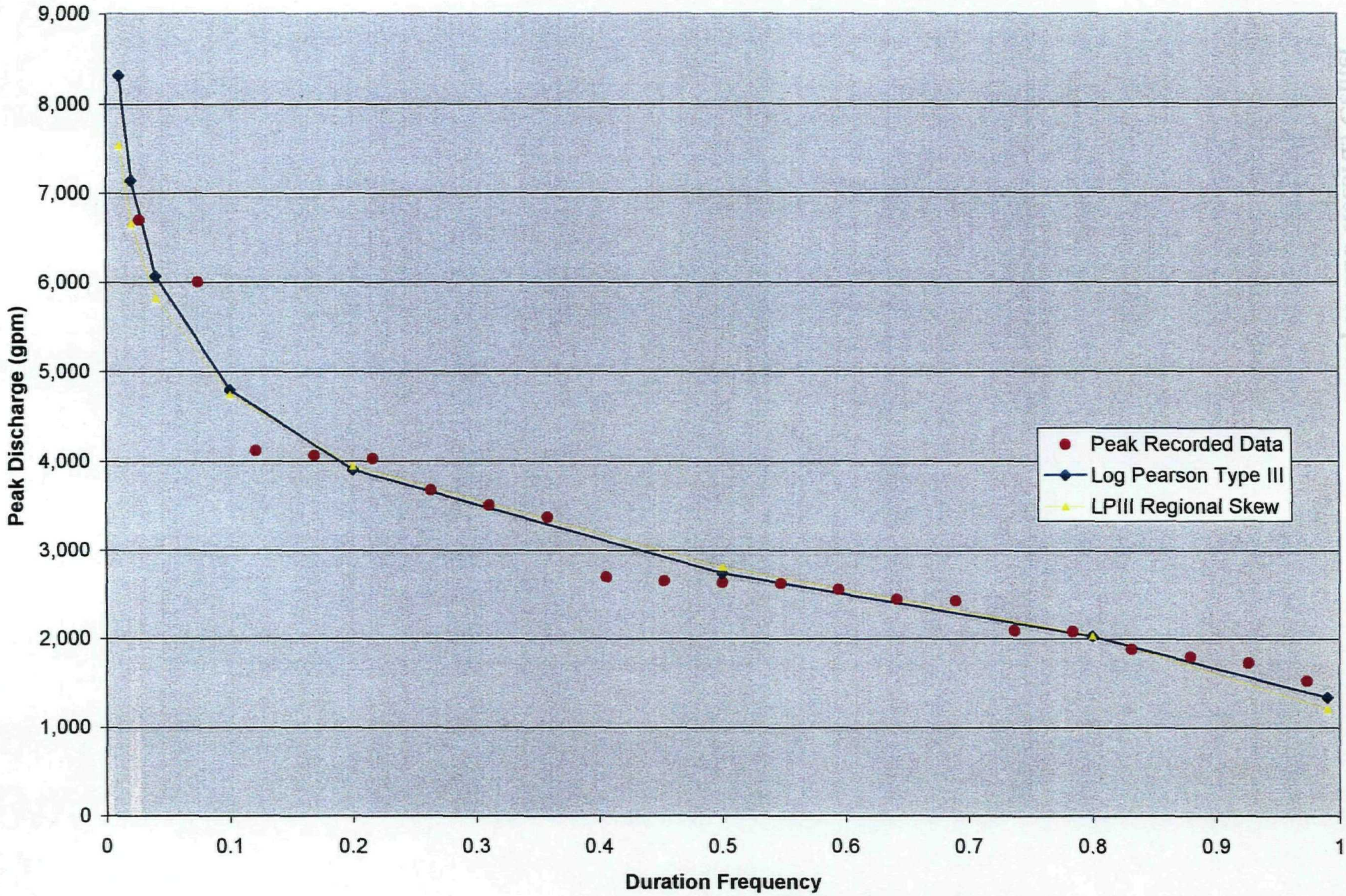
Average	3075	3.4538
Count	21	21
Std. Dev.	1348	0.1710
Skew	1.424	0.5575

Peak Recorded Data

KELLOGG TUNNEL

Rank	Gringorton Plotting Position	Gringorton Return Period	Weibull Plotting Position	Weibull Return Period	Blom Plotting Position	Blom Return Period	Year	Peak Discharge (gpm)	Log(Qp)
1	0.02651515	37.7	0.045455	22.0	0.02830	35.3	1973	6,700	3.826075
2	0.07386364	13.5	0.090909	11.0	0.07547	13.3	1974	6,000	3.778151
3	0.12121212	8.3	0.136364	7.3	0.12264	8.2	1982	4,114	3.614264
4	0.16856061	5.9	0.181818	5.5	0.16981	5.9	1981	4,062	3.60874
5	0.21590909	4.6	0.227273	4.4	0.21698	4.6	1996	4,025	3.604808
6	0.26325758	3.8	0.272727	3.7	0.26415	3.8	1979	3,674	3.565139
7	0.31060606	3.2	0.318182	3.1	0.31132	3.2	1980	3,503	3.54444
8	0.35795455	2.8	0.363636	2.8	0.35849	2.8	1989	3,369	3.527558
9	0.40530303	2.5	0.409091	2.4	0.40566	2.5	1978	2,694	3.430398
10	0.45265152	2.2	0.454545	2.2	0.45283	2.2	1990	2,649	3.423132
11	0.5	2.0	0.500000	2.0	0.50000	2.0	1983	2,632	3.420286
12	0.54734848	1.8	0.545455	1.8	0.54717	1.8	1988	2,619	3.418209
13	0.59469697	1.7	0.590909	1.7	0.59434	1.7	1984	2,553	3.407051
14	0.64204545	1.6	0.636364	1.6	0.64151	1.6	1986	2,444	3.388057
15	0.68939394	1.5	0.681818	1.5	0.68868	1.5	1985	2,428	3.385249
16	0.73674242	1.4	0.727273	1.4	0.73585	1.4	1987	2,090	3.320146
17	0.78409091	1.3	0.772727	1.3	0.78302	1.3	1997	2,075	3.317064
18	0.83143939	1.2	0.818182	1.2	0.83019	1.2	1975	1,880	3.274158
19	0.87878788	1.1	0.863636	1.2	0.87736	1.1	1998	1,799	3.255029
20	0.92613636	1.1	0.909091	1.1	0.92453	1.1	1999	1,730	3.237994
21	0.97348485	1.0	0.954545	1.0	0.97170	1.0	1995	1,529	3.184422

KELLOGG TUNNEL - Peak Flow Log Pearson Type III Distribution
Duration Frequency



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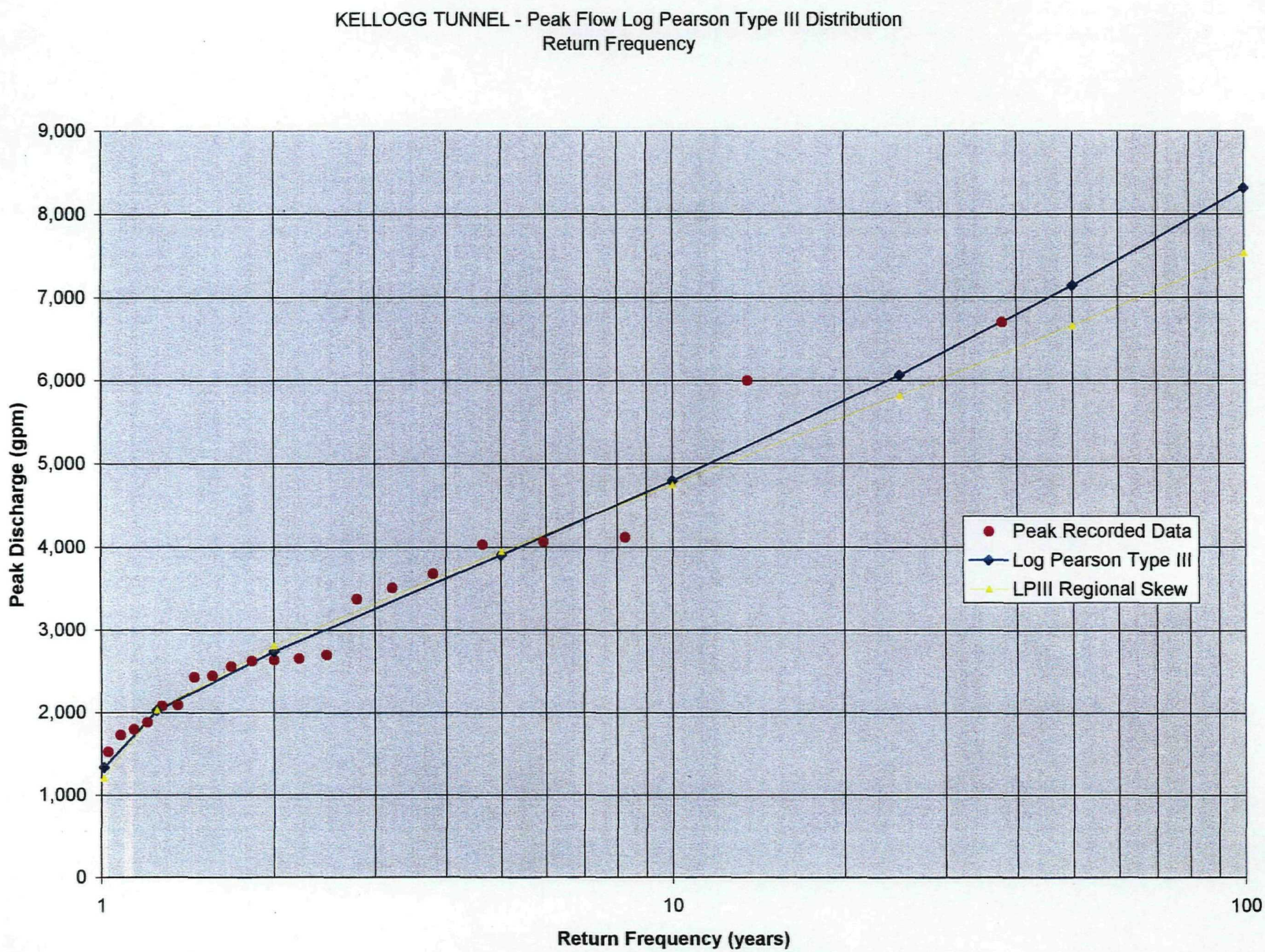

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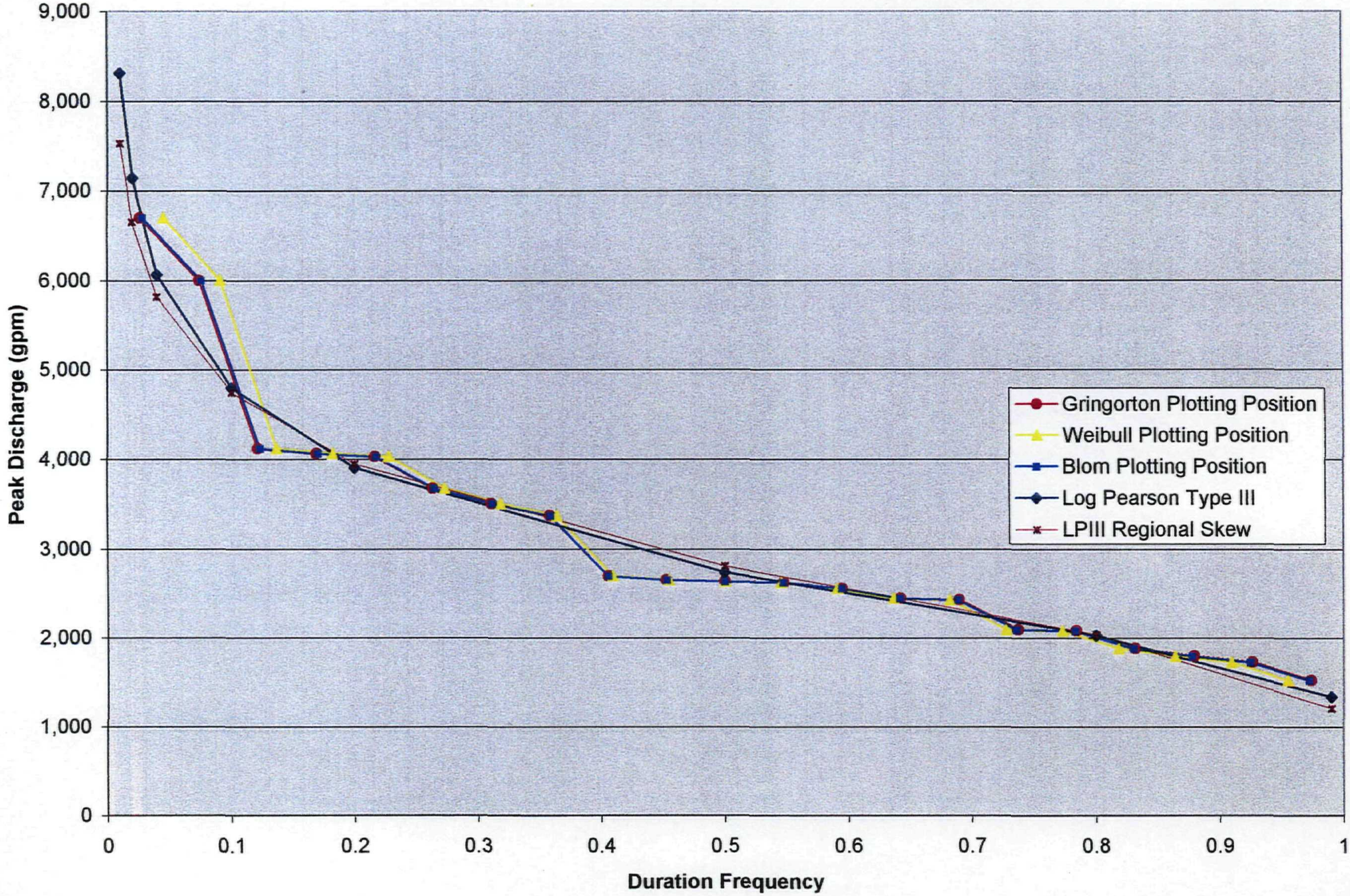
KELLOGG TUNNEL - Peak Flow Log Pearson Type III Distribution
Duration Frequency



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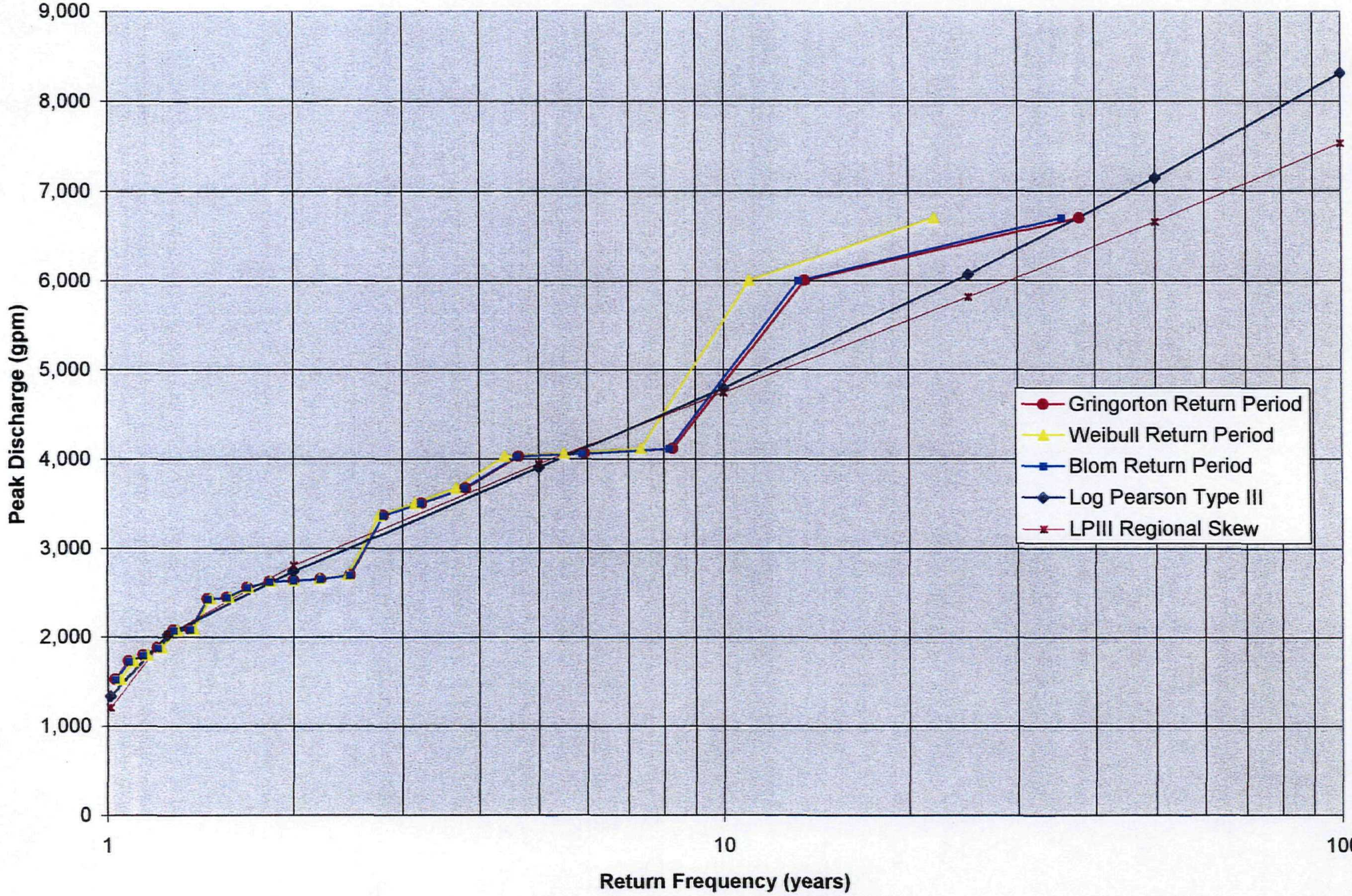
KELLOGG TUNNEL - Peak Flow Log Pearson Type III Distribution
Return Frequency



Log Pearson Type III

Return Period	Probability	K Value	Peak Discharge		
1.0101	0.99	-2.424	405	-2.326	-2.472
1.25	0.8	-0.834	949	-0.842	-0.830
2	0.5	0.022	1501	0.000	0.033
5	0.2	0.847	2336	0.842	0.850
10	0.1	1.266	2923	1.282	1.258
25	0.04	1.704	3695	1.751	1.680
50	0.02	1.981	4287	2.054	1.945
100	0.01	2.227	4890	2.326	2.178

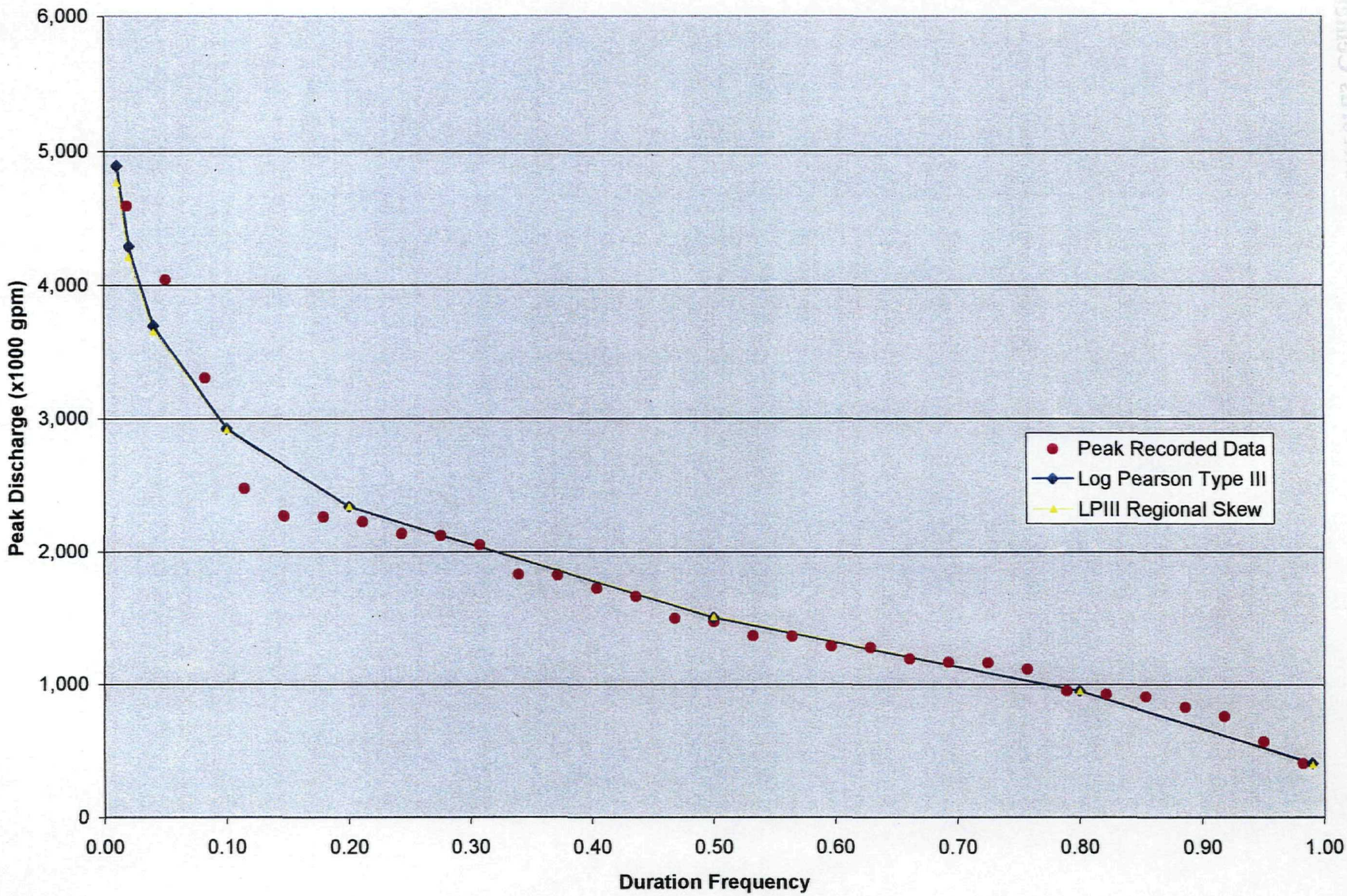
Reg/ Weight Skew	K Value	Peak Q	Q Differenc e
-0.2	-2.472	395	10
-0.2	-0.830	951	-2
-0.2	0.033	1510	-9
-0.2	0.850	2339	-3
-0.2	1.258	2910	12
-0.2	1.680	3648	46
-0.2	1.945	4205	82
-0.2	2.178	4764	127

Average	3.1713
Count	31
Std. Dev.	0.2326
Skew	-0.1337

Peak Recorded Data

Rank	Gringorton Plotting Position	Gringorton Return Period	Weibull Plotting Position	Weibull Return Period	Blom Plotting Position	Blom Return Period	Year	PINEHURST Peak Discharge (x1000 gpm)	Log(Qp)
1	0.01799486	55.6	0.031250	32.0	0.02000	50.0	1974	4,592	3.661965073
2	0.05012853	19.9	0.062500	16.0	0.05200	19.2	1996	4,039	3.606295358
3	0.08226221	12.2	0.093750	10.7	0.08400	11.9	1982	3,302	3.518738843
4	0.11439589	8.7	0.125000	8.0	0.11600	8.6	1997	2,473	3.393204447
5	0.14652956	6.8	0.156250	6.4	0.14800	6.8	1979	2,269	3.355792474
6	0.17866324	5.6	0.187500	5.3	0.18000	5.6	1991	2,262	3.354483385
7	0.21079692	4.7	0.218750	4.6	0.21200	4.7	1971	2,223	3.347023924
8	0.24293059	4.1	0.250000	4.0	0.24400	4.1	1981	2,138	3.329961963
9	0.27506427	3.6	0.281250	3.6	0.27600	3.6	1969	2,123	3.326880194
10	0.30719794	3.3	0.312500	3.2	0.30800	3.2	1972	2,052	3.312202188
11	0.33933162	2.9	0.343750	2.9	0.34000	2.9	1976	1,825	3.261352535
12	0.3714653	2.7	0.375000	2.7	0.37200	2.7	1995	1,818	3.259507871
13	0.40359897	2.5	0.406250	2.5	0.40400	2.5	1975	1,720	3.235418498
14	0.43573265	2.3	0.437500	2.3	0.43600	2.3	1986	1,659	3.219872688
15	0.46786632	2.1	0.468750	2.1	0.46800	2.1	1990	1,495	3.174497082
16	0.5	2.0	0.500000	2.0	0.50000	2.0	1984	1,468	3.166616796
17	0.53213368	1.9	0.531250	1.9	0.53200	1.9	1985	1,362	3.134119229
18	0.56426735	1.8	0.562500	1.8	0.56400	1.8	1993	1,360	3.133495477
19	0.59640103	1.7	0.593750	1.7	0.59600	1.7	1970	1,286	3.109321449
20	0.6285347	1.6	0.625000	1.6	0.62800	1.6	1978	1,276	3.105905461
21	0.66066838	1.5	0.656250	1.5	0.66000	1.5	1989	1,189	3.075298722
22	0.69280206	1.4	0.687500	1.5	0.69200	1.4	1983	1,165	3.0664415
23	0.72493573	1.4	0.718750	1.4	0.72400	1.4	1987	1,160	3.064559585
24	0.75706941	1.3	0.750000	1.3	0.75600	1.3	1988	1,113	3.046504529
25	0.78920308	1.3	0.781250	1.3	0.78800	1.3	1968	949	2.977104608
26	0.82133676	1.2	0.812500	1.2	0.82000	1.2	1980	923	2.965415054
27	0.85347044	1.2	0.843750	1.2	0.85200	1.2	1998	907	2.957404218
28	0.88560411	1.1	0.875000	1.1	0.88400	1.1	1994	826	2.916870671
29	0.91773779	1.1	0.906250	1.1	0.91600	1.1	1973	757	2.87919752
30	0.94987147	1.1	0.937500	1.1	0.94800	1.1	1992	565	2.752423393
31	0.98200514	1.0	0.968750	1.0	0.98000	1.0	1977	400	2.602300776

PINEHURST - Peak Flow Log Pearson Type III Distribution
Duration Frequency



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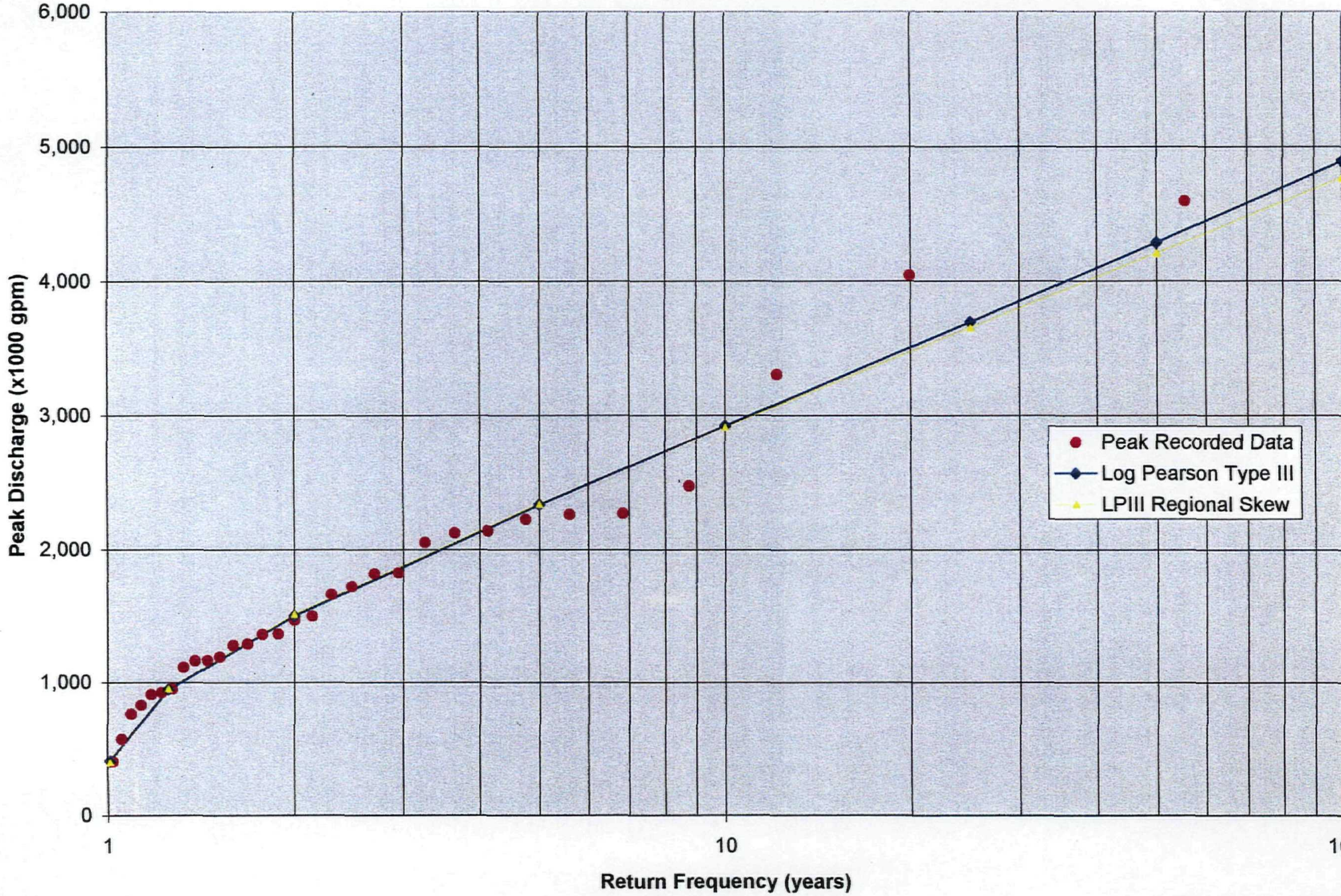
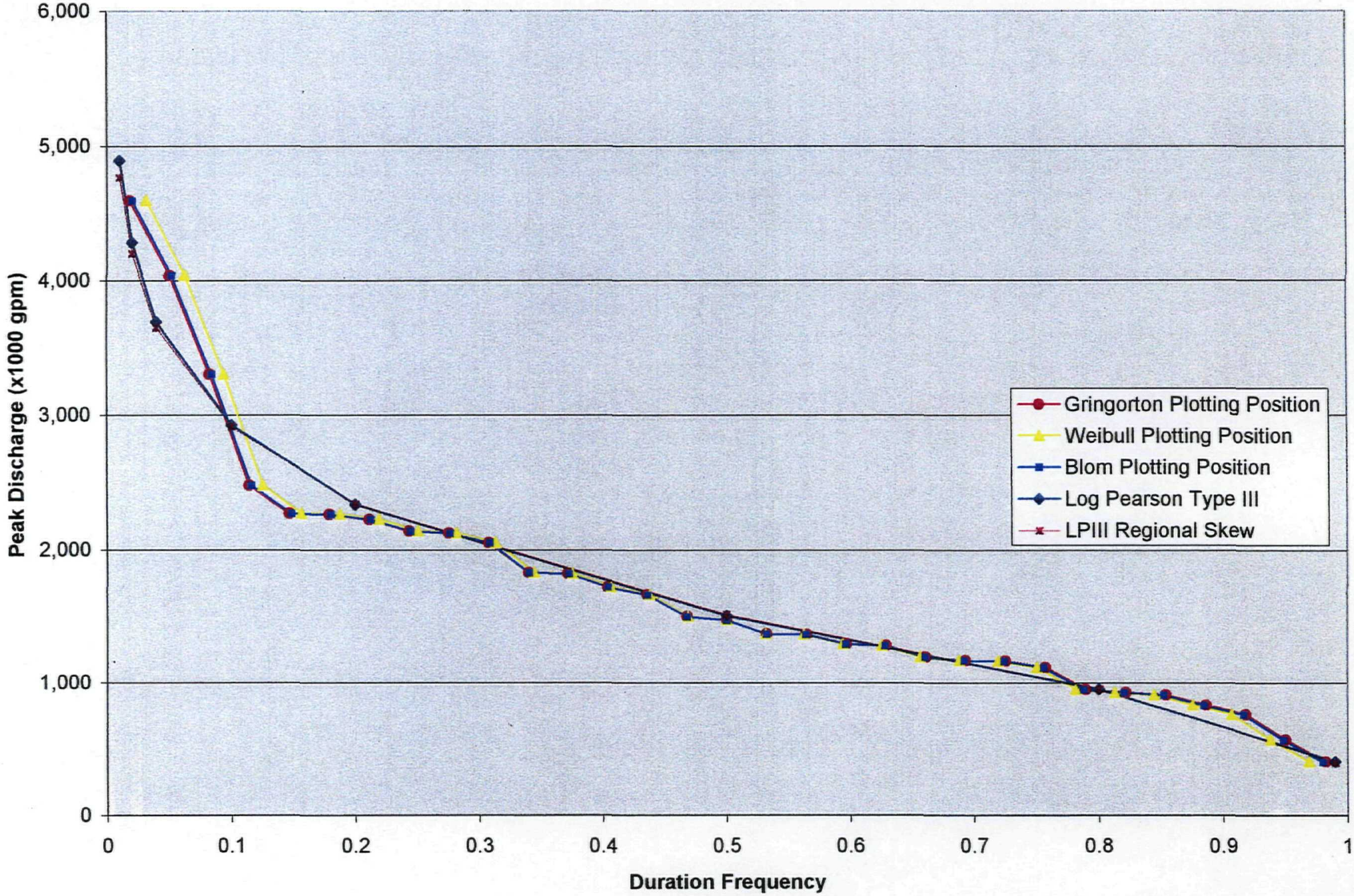
PINEHURST - Peak Flow Log Pearson Type III Distribution
Return Frequency



PINEHURST - Peak Flow Log Pearson Type III Distribution
Duration Frequency



PINEHURST - Peak Flow Log Pearson Type III Distribution
Return Frequency